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NORTH AMERICA'S MIDCONTINENT RIFT

Augmented Reality for Earth Science

Quirky Geoscience Tunes

Future of AGU Meetings

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On the Cover

A cliff of North America's Midcontinent Rift, overlooking Lake Superior. Credit: iStock.com/jimkruger.

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Tanzanian Volcanoes May Hold Helium Ready for the Taking

Peter Barry

Helium bubbles up through a hot spring in the Rift Valley of Tanzania.

Volcanologist Peter Barry spent years in the Great Rift Valley of Tanzania as a graduate student studying the noble gases released at hot springs, asking broad scientific questions about the region's nearby volcanoes. But unbeknownst to Barry, beneath his feet lay a precious supply of helium gas potentially more concentrated than any reservoir of the element previously discovered.

"The helium was under our noses the whole time, but we weren't thinking about developing resources and were instead asking broader scientific questions about the volcanoes themselves," said Barry, now a postdoctoral researcher in the Department of Earth Sciences at University of Oxford in the United Kingdom.

A team led by Barry recently found evidence for unusually rich helium deposits across the Rift Valley. One apparent reservoir of the gas offers the unheard-of helium concentration of more than 10% by volume. At sites around the valley, the researchers more commonly found helium in the 1.5%–2.5% range.

A Unique Helium Deposit

The world's 33 helium plants extract the element from natural gas, and helium rarely composes more than 0.7% of the total volume. At large natural gas plants in Qatar, helium concentrations sometimes barely reach 0.05%. In contrast, the more highly concentrated helium in Tanzania appears to be mixed mainly with nitrogen, from which helium is more easily separated.

Helium finds wide use as an ultracold liquid in MRI equipment and other medical devices, spacecraft, and scientific facilities such as particle accelerators. The gas changes to a liquid at the extraordinarily low temperature of −269°C and therefore can be used to cool superconducting magnets and other devices. An MRI scanner contains about 1500–2000 liters of liquid helium to cool its magnets.

The new findings of high-concentration helium may profoundly alter the way the element is extracted from the Earth, according to Barry and other helium experts.

"In Tanzania we can drill a well to target just helium. This is...unique—no one else is doing this," said Barry. His team presented evidence of the high-concentration helium reservoirs on 27 June at the Goldschmidt Conference in Yokohama, Japan. The findings also may clarify how volcanic activity influences the richness and locations of natural helium reservoirs.

A Goldilocks Zone

Barry returned to Tanzania to survey helium reserves at the request of Helium One Ltd., a start-up mining company that was registered in the British Virgin Islands in 2015. The company had found a 1967 scientific paper indicating rich helium deposits in the Rift Valley's thermal springs (see http://bit.ly/HeRift) and wanted Barry and his colleagues to verify the findings.

To test helium concentrations, the researchers took samples of gas bubbling from the hot springs reservoirs by means of a funnel connected to a copper tube. Surface gas samples typically reflect true subsurface concentrations, Barry told *Eos*.

Samples taken within 20–30 kilometers of a trio of active volcanoes contained helium at a concentration of only 0.0005%, according to Barry. However, helium concentrations in samples taken in the Rungwe area of the Rift Valley, about 150 kilometers from those volcanoes, reached as high as 2.5%. Less than 50 kilometers from the Hanang and Labait volcanoes, in another Rift Valley region called Balangida, the team measured the extraordinary concentrations of 10.2% helium.

On the basis of the findings, Barry and his colleagues suggest that most deposits of concentrated helium gas occupy a Goldilocks zone that lies at a "just right" distance from volcanoes. Volcanic heat can liberate helium from ancient rock. However, the researchers speculate, volcanic gases like carbon dioxide (CO_2), abundant near erupting volcanoes, may then dilute the helium, driving concentrations down. The location of the Goldilocks zone would depend on factors such as how active

Peter Barry

A geologist with Helium One takes gas samples at a hot spring using a funnel that feeds into an impermeable copper tube.

the volcanoes are and which volcanic gases are present, Barry said.

"If volcanic gases are causing dilution, then you will see high CO_2 and low helium closest to the active volcano. Farther away, the helium will dominate. This is what we are seeing," said Diveena Danabalan, a Ph.D. student from Durham University, also in the United Kingdom, who worked with Barry on the sampling. Because Hanang and Labait are relatively inactive volcanoes for the region, they might not greatly dilute helium by producing large amounts of CO_2, Danabalan added.

Helium Glut

The Tanzania find comes on the heels of a period of severe instability in the global helium market, which was valued in 2015 at $700 million. Contrary to the popular perception that helium stocks are running out, the world supply currently significantly outstrips demand. That abundance follows a shortage from 2011 to 2013 when several new helium production sites delayed opening, maintenance work at natural gas plants idled some existing suppliers, and remaining sites held production steady because they lacked costly cold-temperature storage to hold additional output.

In response to the shortage, producers of MRI scanners began recovering and recycling helium. Recession in Europe and Asia also reduced demand just as the delayed sites began to increase supply. Adding to the oversupply, new producers have recently come online in the United States and Algeria. Today most helium production sites are running at only 50% capacity, said Ralf Gubler, a senior principal analyst covering industrial gases at IHS Chemical in Zurich, Switzerland.

If the Tanzanian measurements lead to accessible reservoirs of helium not mixed with natural gas, those new sources may prevent future price shocks like the ones that debilitated past markets, according to Gubler. When a liquefied natural gas plant that's also a helium source requires maintenance or if production stalls, the helium market loses some of its supply, he noted. Tapping reservoirs of helium gas rather than natural gas containing helium might also prove more profitable. "If the helium concentration at the new source in Tanzania is really high, the producers will benefit from lower costs," said Gubler.

The discoveries in Tanzania aren't expected to make a big difference to the world reserves. The estimated 1.53 billion cubic meters of helium gas there would meet only about 9 years of global helium demand, according to Robert Jolley, field manager at the U.S. Federal Helium Reserve in Amarillo, Texas. Rather, "it is the high helium concentrations [that] are significant, as opposed to the total amount of gas, which is not huge compared to other helium-producing regions," said David Hilton, an isotope geochemist at Scripps Institution of Oceanography in La Jolla, Calif.

For now, Josh Bluett, technical director at Helium One Ltd., hesitates to claim too much, noting that "it will require further geophysical surveys and drilling to prove up the potential and to ultimately realize productive helium reserves."

By **Amy Coombs,** Editorial Intern

Bacteria Preserve Record of Earth's Magnetic Fields

Mark A. Wilson

Magnetic minerals, such as the dark stripes of magnetite seen here in beach sand in India, can form layers in sediments.

In the waters of a prehistoric ocean, a minuscule bacterium swims back and forth, seeking food. As it does so, it leaves tiny metallic particles swirling in its wake—some already present in the water column, some excreted as the bacteria's by-products. As the water churns from the motion of other bacteria, some of these particles—magnetic ones—attract each another, coalescing into larger, but still tiny, magnetized crystals of magnetite, goethite, hematite, and other minerals. These iron-rich crystals drift slowly downward to land on the ancient seabed, aligning with the Earth's magnetic field as they're buried by other sediment and eventually locked into place.

A scene much like this has unfolded again recently in a glass experimental vessel holding bacteria-filled water in a Russian laboratory. A team of scientists was curious to see how large the crystals could grow and whether they could become substantial enough to maintain a stable magnetic orientation over millions, or even billions, of years.

Their findings, published recently in *Geophysical Journal International* (see http://bit.ly/FeBacteria), shed light on how sediments gain and retain magnetism.

Answers in Sludge

For their study, the team used "bacteria that are taken from nature, normal groundwater bacteria," said Alexandra Abrajevitch, a paleomagnetist at the Institute of Tectonics and Geophysics of the Russian Academy of Sciences in Khabarovsk, Russia, and lead author on the study. The scientists seeded the vessel of water with iron, food, and sand. Then they waited.

Two years later, when the team looked at the reddish sludge that had formed at the bottom of their experiment, they found that the sample contained large crystals of magnetite and goethite. These are stable minerals, capable of carrying a magnetic signature over long periods of time. The team also found lepidocrocite, a magnetically unstable mineral that can transform into more stable forms over time.

According to the paper, tests of the sludge's magnetism revealed that it contained a broad range of particle sizes. Some were tiny and unstable like those found in previous experiments, but many were more than 30 nanometers long, large enough to hold a magnetic direction for as long as billions of years. These particles confirmed for the researchers that given enough time, bacteria could prompt larger and larger magnetic crystals to grow in their environment, just by moving and stirring up the water and excreting iron-rich waste.

In ancient waters, large particles recorded the direction of the Earth's magnetic field when they settled on the seabed. Most of the stable particles aligned with the Earth's magnetic field. Sediment settled on top of them, holding them in place. The different layers in sedimentary rock provide a continuous timeline of the shifting strength and direction of the magnetic field over time—"almost like a bar code," according to David Heslop, a geophysicist at the Australian National University in Canberra, Australia, who was not involved with the new study.

Too Small to Be Useful?

Scientists have known for decades that sedimentary rock captures a record of the Earth's magnetic field. But if the new findings published on 13 June are correct, they shed light on the way in which many of Earth's rocks became magnetic, according to Heslop. Researchers had known that magnetic particles could be generated by erosion from iron-rich minerals or the remains of magnetotactic bacteria that create chains of magnetized particles in their bodies to help them navigate. But even though scientists can easily determine whether a rock is magnetic or not, definitively finding the cause of that magnetism—a necessary step if scientists are to glean useful information about Earth's magnetic history—is much more difficult.

If the common bacteria in the experiment could generate stable magnetic particles, he said, a similar process could have been happening throughout Earth's oceans, rivers, and lakes farther back in time than scientists have even looked, back when microbes first became abundant.

Researchers have been searching for these bacterially generated particles for some time, but past studies have found mostly tiny, unstable, microbe-made magnetized particles. Those smallest particles would simply be too tiny to hold a magnetic direction for long.

Heslop explained that when a magnetic particle is too small, a tiny amount of heat can cause its magnetic field to change orientation. The poles of such particles jump in all directions multiple times a second at room temperature. Longer particles would be much more magnetically stable and therefore useful to scientists who want to study what the Earth was like millions of years ago. However,

researchers had no proof that bacteria could produce them.

Because there was no proof that they could be stable, the particles were dismissed as a potential data source. But the authors of the new study say that prior researchers didn't wait long enough for the particles to mature and grow to their full size.

Heslop expects that with this new knowledge in hand, scientists will be able to scan more rocks with better accuracy to find the direction of Earth's ancient magnetic field and to determine the strength of that magnetic field as well. Similar data have been used to track continental drift and discover more about flips and other distortions in the magnetic field similar to those that could disrupt our communications and mapping satellites in the future.

L. M. Kondratyeva

Scientists filled this container with water, groundwater bacteria, iron, food, and sand. Two years later, they found a reddish sludge, visible here, containing mineral crystals large enough to preserve a magnetic signature for billions of years.

Finding the Strength

Scientists have historically had trouble researching the strength of the Earth's ancient magnetic field. Magnetic minerals from different sources and of different sizes vary in how readily they will align with a field, Heslop said. When researchers are looking at a rock's magnetism, they have to know either the strength of the Earth's magnetic field when the rock was formed or how responsive the magnetic alignment of that type of iron-rich particle was to the field. Knowing one can allow researchers to figure out the other. If scientists know the source and magnetic efficiency of the particles, "with a few extra calculations, we can make an estimate of how strong the Earth's magnetic field was at that time," Heslop said.

Because scientists had dismissed particles inadvertently produced by swimming bacteria as too small and unstable to generate this kind of sustained magnetism, they assumed that the rocks' magnetism must have come from other sources, such as eroded magnetic minerals or magnetotactic bacteria.

Figuring out exactly what kinds of particles the majority of bacteria produce and how strongly they align with Earth's magnetic field could help scientists refine their estimates of the strength and orientation of Earth's magnetic field in the deep geologic past. This new experiment was small, Heslop said, but its results may encourage scientists to revisit archives of sedimentary rock samples with new, more reliable information on the origins of their magnetic properties.

By **Elizabeth Deatrick,** Freelance Science Journalist; email: edeatrick@elizabethdeatrick.com

Science Groups Voice Concern for Academics in Turkey

The International Council for Science (ICSU) and other scientific and academic organizations have expressed strong opposition to a reported crackdown on educators and academics in Turkey following the 15 July failed coup d'etat in the country.

The Turkish government has ordered more than 1550 university deans to resign, has fired more than 15,000 teachers and other education staff, and has banned all academics from leaving the country following the coup, according to news reports.

ICSU's 28 July statement (see http://bit.ly/ICSU728), which deplores the coup, expresses "grave concern" about the current situation in Turkey. It urges the Turkish authorities to uphold the civil liberties and academic freedom of educators and of research, to exercise restraint, and to observe the rules of law. The statement calls for Turkey to restore its Principle of Universality of Science, which embraces the free and responsible practice of science. ICSU is a nongovernmental organization comprising 122 national scientific bodies and 31 international scientific unions.

The statement expresses particular concern about reports that academics and educators have lost their positions "in a summary fashion" since the failed coup.

Providing Support for Turkish Scientists

Leiv Sydnes, chair of ICSU's Committee on Freedom and Responsibility in the conduct of Science (CFRS), told *Eos* that the group's statement helps to shine a spotlight on the issue.

REUTERS/Osman Orsal

The view through a damaged window at the police headquarters in Ankara, Turkey, on 18 July, a few days after a failed coup attempt.

"It is very important for the Turkish scientists to see that people outside the country care about their situation," said Sydnes, a professor of chemistry at the University of Bergen in Norway, who wrote the draft for the ICSU statement. "To what extent [the statement] has an impact on the politicians and the political development, that is more a question of belief than anything, I think, but we can hope [for] the best."

He added that he thinks Turkey's leadership lacks trust in the nation's scientists. "I think they are afraid of [the scientists'] ability to talk freely about a number of issues," Sydnes explained.

Some Turkish scientists expressed thanks for ICSU's statement and for "being watchdogs for what is taking place," according to Sydnes.

Sydnes said that ICSU previously expressed concern about academic freedom in Turkey. A January 2016 letter signed by ICSU and others (see http://bit.ly/Turkeyscholars) expressed concern about "widespread pressures" on members of the country's higher education and research communities. Sydnes said that the pressure has intensified in the current situation.

Other scientific organizations issuing statements about the current situation in Turkey include the European University Association, the International Astronomical Union, and national academies in the United Kingdom (see http://bit.ly/EUATurkey, http://bit.ly/IAUTurkey, and http://bit.ly/UKTurkey).

At press time, the Turkish government had not responded to a request from *Eos* for comment.

By **Randy Showstack,** Staff Writer

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- NASA's New Asteroid Sampler Will Illuminate Solar System's History (http://bit.ly/EOS_asteroid-sampler)
- Climate Scientists' New Hurdle: Overcoming Climate Change Apathy (http://bit.ly/EOS_climate-change-apathy)

Amoeba People Sing Quirky Tunes About Geoscience

The Amoeba People are redefining Earth and space science education, one song at a time.

With humorous, catchy, and offbeat numbers about geophysics that mix G-rated pop, rock, folk, jazz, hip-hop, and other genres, the band, based in Lakewood, Calif., recently released its fourth album and saw its top music video, "Continental Drift," surpass a half million views on YouTube (see http://bit.ly/CDAmoeba).

Guitarist Ray Hedgpeth, an elementary school teacher who also plays the banjo, theremin, and other instruments, wrote that song in 2010 while trying to interest his students in the story of Alfred Wegener and plate tectonics. The tune, which includes a boiled down historical take about Wegener, exclaims, "Yee haw! Alfred Wegener! / You are a brilliant, brilliant man! / Continental Drift! Alfred Wegener's theory!"

"The kids went crazy for it, and I began to write more," Hedgpeth told *Eos*. The song led to his forming the Amoeba People that year with drummer Dustin Jordan and bass and keyboard player Ryan Mosley.

Not your average band, the Amoeba People combine studiously researched songs with a wacky mythology that traces them to the planet Crouton, a fictional world 17 light years from Earth whose leaders supposedly sent them here as musical ambassadors charged with gathering scientific data and sending them back home in musical form.

When performing live or on video, the band members dance like dorks and dress in short-sleeve white shirts, narrow ties, and horn-rimmed glasses to fit in with the television transmissions of traditionally clad space science engineers Crouton detected from Earth circa 1962.

The name of the band originates from a colleague of Hedgpeth who mentioned that kids learning to draw at first mostly make "those amoeba people": blobs with arms, legs, and a face. Hedgpeth said that when he saw bandmate Jordan drawing "little green amoeba guys," the band thought "it would be cool if that's what the band was on their home planet but they could shape-shift when they came to Earth and 'take on' a human form."

Music as an Educational Tool

The Amoeba People, who refer to themselves as Meebs, "are moving science education out

Courtesy Amoeba People

The Amoeba People (left to right) Dustin Jordan, Ryan Mosley, and Ray Hedgpeth camping it up for their music video "The Geologists Are Coming."

of the textbook," making science more accessible, and treating scientific knowledge like an art medium, according to Benjamin Dickow, president and executive director of the Columbia Memorial Space Center in Downey, Calif., NASA's memorial to the shuttle *Columbia*. He said the group, which serves as the museum's official house band, has "a punky-surf-rockabilly foundation."

"The Ballad of Carl Sagan" ranks as Dickow's favorite song; its refrain about the astronomer goes, "Straight outta Brooklyn like a comet to the stars / Carl's mind wandered from this pale blue dot of ours."

The Meebs plan to release a music video of the song "involving as many Carl Sagan impersonators as we can muster," Hedgpeth said.

"A Great Jumping-Off Point"

For Jen Parks, an instructor in the Earth and Environmental Sciences Department at the University of Waterloo in Ontario, Canada, the Amoeba People "contribute a novel way to introduce scientific content to undergraduate classes."

Parks uses their songs during her lectures as "a great jumping-off point" to more advanced content and to encourage fun and creativity in the classroom. Parks said that when she first heard their music in 2013, "I couldn't believe someone had written lyrics that were scientifically correct and had put [them] together with such quirky tunes that reminded me of some ska bands I used to listen to when I was younger."

Her favorite song, "The Geologists Are Coming," not only has a campy accompanying video of nerd geologists running down hills and hammering at rocks (see http://bit.ly/GeoAmoeba) but also includes delightfully silly lyrics such as "The geologists are coming! / Yes, they're trudging down the hill. / When they say that mountain's young / They're talking ten to twenty mil."

Parks related that during a recent field trip with her second-year mineralogy class, students in separate minivans sang that song over walkie-talkies while driving between field stops.

Hedgpeth traced the song's title to a 2009 *Wired* magazine article that said staffers at a San Francisco brewpub couldn't take vacation during AGU meetings "because the geologists are coming" (see http://bit.ly/GeoWired).

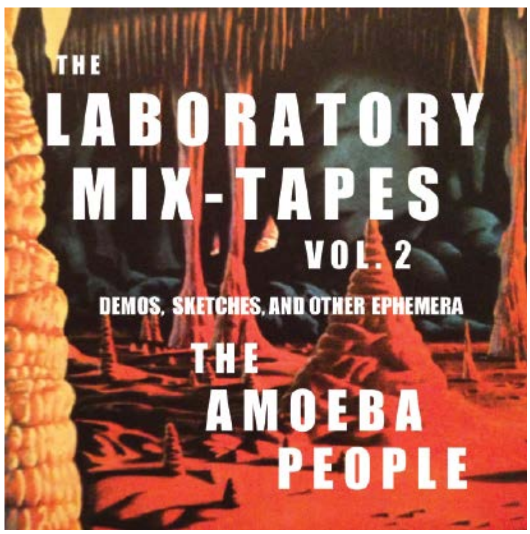
Researching and Writing

As the group's principal songwriter, Hedgpeth said he tries to write songs specifically for primary school students in grades 4–6 that might also hit "the sweet spot" of appealing to college students and others. "Every time I would come up against something in the [Earth science] textbook, it resulted in a new Amoeba People song," he said, adding that he delves deeply into the material and then fact-checks it with geologists and other experts.

"I really, really research the stuff. I really dig deep, and the hard part is you know you are going to leave stuff out" of songs, he said.

Band member Mosley, who works as an electrician, said that he and Jordan have been excited about the ideas Hedgpeth comes up with for music with a scientific slant. "It's kind of a niche that we're trying to fill that we don't feel like anyone else is doing," he said.

"Literally, you have a whole world to draw off of," added Jordan, a delivery driver and former heavy metal drummer for a different band who does artwork for the group's album covers. "I'm just really blown away that you guys in the geology community even like what we're doing," he said.



Courtesy Amoeba People

Songs on the latest album by the Amoeba People include "Who's a Geophysicist?" and "Goodbye Pangaea."

"A Head-Hummer Tune"

Paleontologist Scott Brande counts himself among those fans. Brande, an associate professor at the University of Alabama at Birmingham, discovered the band's "Continental Drift" music video a few years ago while searching for interesting material for an introductory geology course he teaches.

"It's a head-hummer tune. You can't get it out of your head. [The students] loved it," Brande said. But more important, to him, the video serves as an effective learning tool that does more than burn up a few minutes of class time.

The Amoeba People "had done their homework," Brande said, noting that the educational content in their music video "corresponded to and overlapped with" a lot of the material he was talking about in class.

Musical Influence

Musicologist Barret Hansen, better known as Dr. Demento, also sings the praises of the Meebs, who draw influences from a variety of musicians, including the Beatles, Devo, and the Kingston Trio.

Dr. Demento, who provided then teenager "Weird Al" Yankovic with his first media exposure, said that the band can generally be compared with music greats like humorist Tom Lehrer or with musicians who make music "that's specifically for kids to use their brains with."

"It's not just mindless repetition of cartoon songs, and it's not based on stuff that they've seen on television. [The Amoeba People] have created their own little world," he said.

During his Internet show's recent Earth Day set, Dr. Demento played the band's song "Seismograph," which squeezes in concise definitions of *P* and *S* waves (see http://bit.ly/DementoED).

The band's first song featured on a Dr. Demento show, "Cosmology, Your Futon and You," features lyrics including "And you're sitting on your futon / And your thoughts turn to cosmology." Hedgpeth said that the Meebs plan soon to release a music video of that song while the band also works on its next album and explores a possible science television show.

"Dear Pluto," a tribute to the downgraded planet, ranks as another of the doctor's favorites by the band. The lyrics include "And I'd like to reassure you / That no matter how you're categorized / You're still our favorite object in the night sky."

"That's certainly one of their talents, creating amusing lyrics with original and articulate word play. Weird Al does that too," Dr. Demento said. "That's real important."

The other important thing, Hedgpeth said, is telling "momentous stories in Earth science [that] nobody knows about."

"There are many, many stories and many concepts that are easy to grasp and fun" but that don't get a lot of attention, he said, "and so that's the area we want to fill."

By **Randy Showstack,** Staff Writer

New Insights into North America's Midcontinent Rift

By Seth Stein, Carol Stein, Jonas Kley, Randy Keller, Miguel Merino, Emily Wolin, Douglas Wiens, Michael E. Wysession, Ghassan Al-Equabi, Weisen Shen, Andrew Frederiksen, Fiona Darbyshire, Donna Jurdy, Greg Waite, William Rose, Erika Vye, Tyrone Rooney, Robert Moucha, and Eric Brown

The Midcontinent Rift has characteristics of a large igneous province, causing geologists to rethink some long-standing assumptions about how this giant feature formed.

Some of the Midwest's most scenic vistas are the black volcanic cliffs that tower above the brilliant blue waters of Lake Superior's north shore. How these formed more than a billion years ago is an amazing story, illustrating one of plate tectonics' most important processes: how continents form and break up.

Over geologic time, continents collide and fuse together. They also split apart, along rifts.

Rifts are linear features along which continents stretch. When a rift succeeds, the continent splits, and a new ocean basin forms between the two parts of the continent. Some

A view of the shore of Lake Superior from Shovel Point in Minnesota's Tettegouche State Park.

Spring Images / Alamy Stock Photo

Cliffs of 1.1-billion-year-old volcanic rocks from the Midcontinent Rift in Tettegouche State Park in Minnesota tower above the brilliant blue waters of Lake Superior.

rifts, however, fail to develop into seafloor spreading centers and instead leave major relict structures within continents—"fossils" preserving the geologic environments in which they formed.

The cliffs on the shores of Lake Superior—and the lake itself—are part of such a fossilized rift. Called the Midcontinent Rift (MCR), this 3000-kilometer-long feature, made of 1.1-billion-year-old igneous and sedimentary rocks, extends underground across the central United States. It stands as one of the best examples of a failed rift (Figure 1).

However, a puzzle remains. The MCR's igneous rocks tell of magma pools far more vast than what one would expect in a failed rift. Why was the MCR so magma rich? Scientists are beginning to tease out answers.

The MCR's igneous rocks tell of magma pools far more vast than what one would expect in a failed rift.

Formation at a Plate Boundary

The traditional view of the formation and evolution of the MCR involved two premises. First, the MCR formed within Laurentia, the core of North America that assembled in the Precambrian era. Second, the MCR failed to split the continent because compression from a mountain-building episode ended the extension and volcanism. This mountain building, called the Grenville orogeny, finished about 980 million years ago and was associated with the assembly of Laurentia and other continental blocks into the supercontinent of Rodinia.

However, a new view of the MCR emerges from studies catalyzed by the National Science Foundation's EarthScope program. One of this program's goals is "to integrate geological and geophysical data to understand the growth and modification of North America over billion-year time scales" (see http://www.earthscope.org/).

The new view begins from reanalysis of gravity data, which show that the MCR extends farther south than previously thought. The east arm (Figure 1) had been assumed to end in Michigan at the Grenville Front, the westernmost deformation associated with the Grenville orogeny. However, this arm now appears to extend along the previously enigmatic East Continent Gravity High, which now seems to be part of the MCR. The arm stops at what scientists believe to be a fossil continental margin, where the Amazonia craton (Precambrian rock now found in northeastern South America) rifted from Laurentia (Figure 1b).

Hence the MCR probably formed during this rifting and failed once seafloor spreading between the major plates was established [*Stein et al.*, 2014]. In this view, the MCR's arms were boundaries of a microplate within a plate boundary zone [*Merino et al.*, 2013], similar to the arms of today's East African Rift, where microplates exist in the zone where Africa is splitting into two major plates (Figure 1c). Once seafloor spreading between the major plates is fully established in the East African Rift, some of the microplate boundaries should stop spreading and remain within the continents as failed rifts.

The MCR formed in a similar way, as Laurentia and Amazonia split apart.

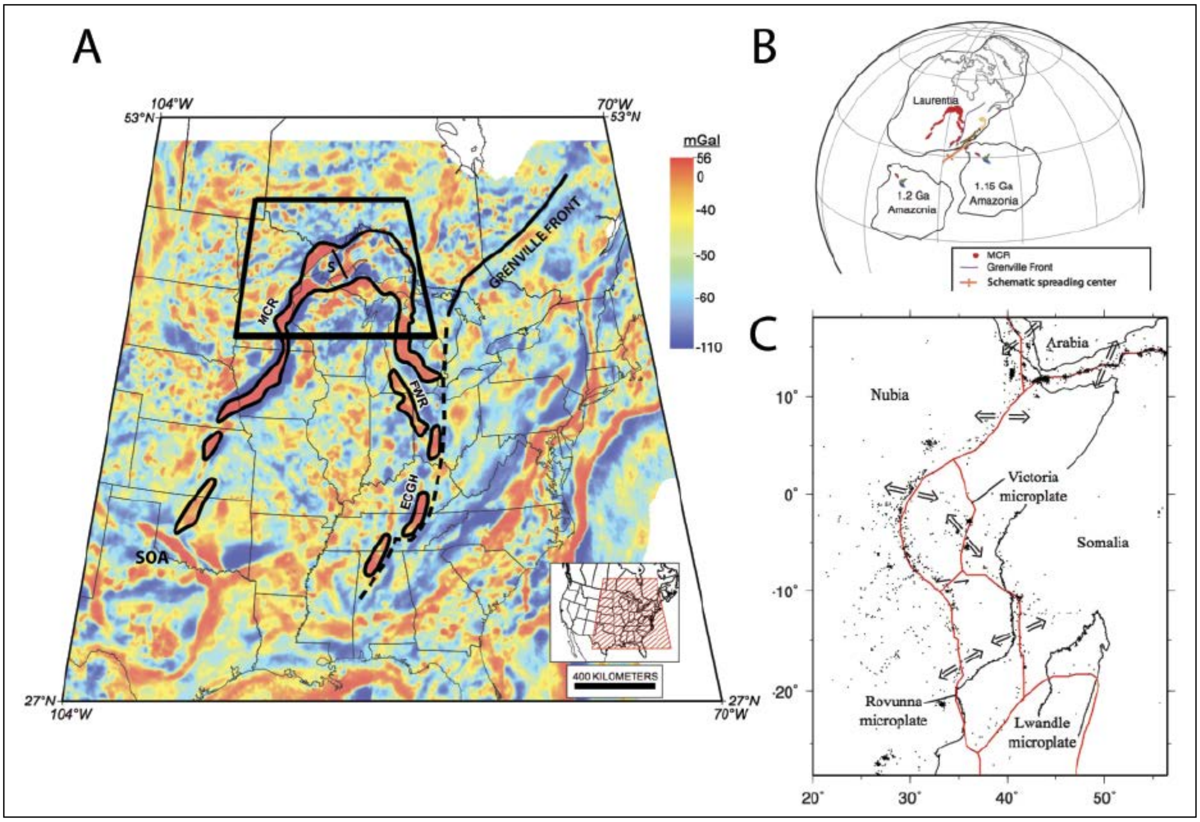


*Fig. 1. (a) Gravity map showing the Midcontinent Rift (MCR). The west arm extends southward from Lake Superior to at least Oklahoma along the Southern Oklahoma Aulacogen (SOA). The east arm goes through Michigan and extends along the Fort Wayne Rift (FWR) and East Continent Gravity High (ECGH) to Alabama [*C. A. Stein et al., *2015]. The Grenville Front is shown by a solid line where observed and by a dashed lined where inferred. "S" shows the location of the seismic line across Lake Superior in Figure 2a. The box shows the approximate area of the Superior Province Rifting EarthScope Experiment (SPREE). (b) Schematic illustration of MCR forming as part of the rifting of Amazonia from Laurentia. (c) Africa rifting into major plates and microplates [*Stein et al., *2014].*

Paleomagnetic studies show that Laurentia's motion changed dramatically when the MCR formed. As volcanic rocks cooled, magnetic minerals aligned with Earth's magnetic field, recording changes in the plate's motion. Such changes are often found in the paleomagnetic record when continents rifted apart. As part of the rifting, the MCR formed and began extending. The region between the MCR's two spreading arms was forced to move away from the rest of Laurentia as a microplate.

A Hybrid Rift

Dense volcanic material fills the MCR. This large, concentrated mass exerts a greater gravitational pull than the areas around it, resulting in what's known as a positive gravity anomaly. In contrast, typical continental rifts have negative anomalies because they are filled primarily with low-density sedimentary rock.

Tracing the gravity anomaly shows that the MCR's arms have characteristic geometries of rifts—linear depressions that formed as plates pulled apart and that filled with sedimentary and igneous rocks. These depressions often evolve into plate boundaries.

Calculating the volume of volcanic rock causing this positive gravity anomaly reveals something interesting about the MCR. It is also a large igneous province (LIP), a region of extensive volcanism associated with upwelling and melting of deep mantle materials. MCR volcanics are significantly thicker than those at other LIPs because magma was deposited within a narrow rift rather than across a broad surface. Hence the MCR is a hybrid with the geometry of a rift but the igneous rock volume of an LIP [*C. A. Stein et al.,* 2015].

How Did This Hybrid Evolve?

Reflection seismic data (Figure 2a) across Lake Superior [*Green et al.,* 1989] show how this unusual combination evolved. The MCR is a basin between dipping faults that contains volcanic rocks up to 20 kilometers thick, overlain by about 5–8 kilometers of sedimentary rocks. The lower volcanic layers truncate toward the basin's north side, indicating that they were deposited while the rift was extending by motion on the northern fault. The upper volcanic layers and overlying sedimentary rocks dip from both sides and thicken toward the basin center, indicating that they were deposited after extension ended, as the basin continued to subside. Radiometric dating shows that the volcanic rocks are about 1.1 billion years old.

Another seismic line to the east shows a similar sequence but with extension on the southern fault. Basins produced by extension on only one side are called half gra-

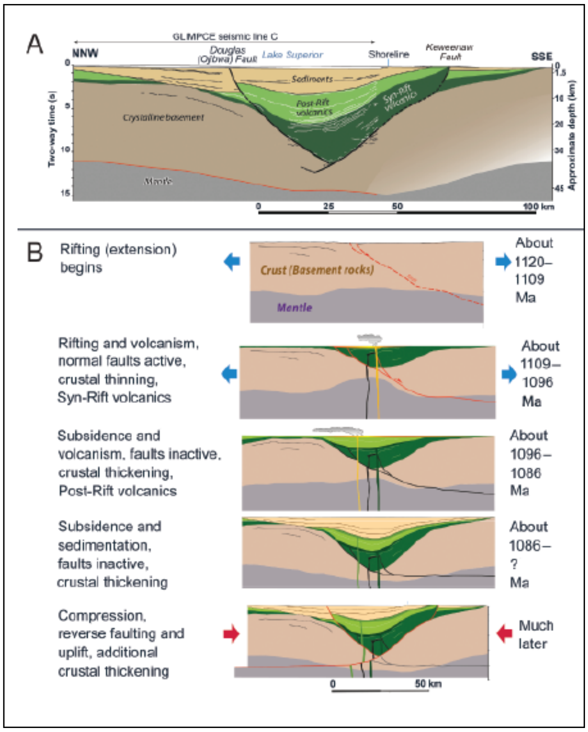


*Fig. 2. (a) Interpreted seismic reflection section across Lake Superior, showing MCR structure. GLIMPCE = Great Lakes International Multidisciplinary Program on Crustal Evolution. (b) Model of MCR evolution. The crust thinned in the rifting stage, rethickened during the postrift phase, and thickened further because of the later basin inversion [*C. A. Stein et al., *2015].*

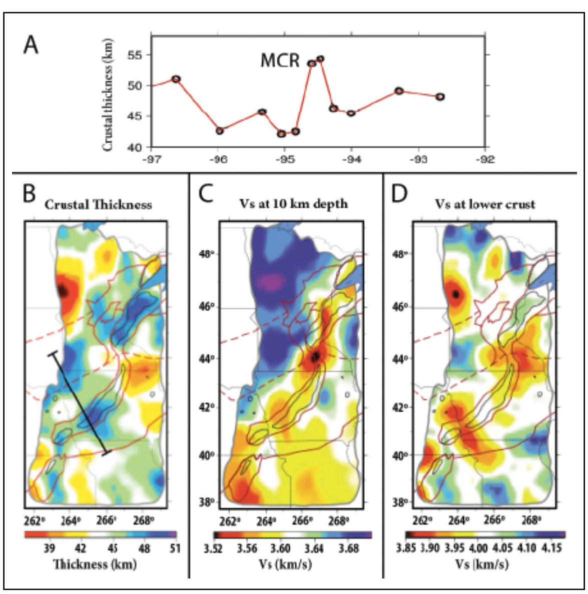


*Fig. 3. Different seismological data show various aspects of the MCR's structure. Crustal thickening beneath the MCR's west arm is shown by (a) receiver functions [*Moidaki et al., *2013] and (b) surface wave tomography [*Shen et al., *2013]. The line in Figure 3b shows the location of the profile in Figure 3a. Shear-wave velocities (Vs) show that the surface waves capture (c) the MCR's low-velocity sedimentary rocks but not (d) the underlying volcanic rocks.*

bens (Figure 2a), so the MCR is a sequence of alternating half grabens, similar to what's found today along the arms of the East African Rift.

Working backward from the geometry of the volcanic and sedimentary rock layers seen today provides an evolutionary model of the feature (Figure 2b). The MCR began as a half graben filled by flood basalts. After rifting (extension) stopped, the basin further subsided, accommodating more flood basalts. After volcanism ended, subsidence continued, accompanied by sedimentation. The crust depressed and flexed under the load of the basalt and sedimentary rocks.

Long after subsidence ended, the area was compressed—a process called basin inversion—which reversed motion on the faults and activated new ones. The original crust thinned during rifting as the crust stretched, rethickened during the postrift phase because of the added volcanics and sediments, and thickened further because of the compression when the basin inverted. If the model is correct, then crustal thickness along the MCR should vary with the amounts of extension and volcanism and the amount and direction of compression applied to that portion of the MCR.

Surprises from Seismic Imaging

New insights on MCR come from data from EarthScope seismometers in the transportable array that "rolled" across the United States, the Superior Province Rifting EarthScope Experiment (SPREE) flexible array [*Stein et al.*, 2011; *Wolin et al.*, 2015], and Canadian seismic stations.

Seismic models covering much of the rift are being developed with these data [*Shen et al.*, 2013; *Bollmann et al.*, 2014; *Al-Eqabi et al.*, 2015; *Zhang et al.,* 2015; *Frederiksen et al.*, 2015]. As expected from the Lake Superior data, crust in the MCR's west arm is thicker than its surroundings (Figures 3a and 3b) and is composed of sedimentary rocks underlain by layered volcanic rocks. Combining the results with gravity and seismic reflection data gives views of the MCR's crustal thickness and structure that will better constrain models of its evolution [e.g., *Levandowski et al.,* 2015].

These studies have already yielded surprising results. The MCR's dense volcanic rocks appear clearly on gravity, seismic reflection, and receiver function data, which are sensitive to variations in density. However, surface wave tomography (Figures 3c and 3d) "sees" the rift's sedimentary rocks through which seismic waves travel slowly but does not see high velocity in the rift-filling volcanics. The basalt rift fill is presumably denser than the surrounding crust, but the velocities of shear waves traveling through it are similar or slightly lower than those of the surrounding rocks.

Another surprise is that the formation of the MCR left little signature in the upper mantle. Although vast quantities of melt were extracted to fill the MCR, the mantle shows no significant seismic velocity anomalies [*Shen et al.,* 2013; *Bollmann et al.*, 2014]. Unless the mantle beneath the MCR was replaced after the MCR formed, melt depletion seems to have had little effect on seismic velocities. The idea that extracting melt from the mantle would not change the mantle's seismic velocity significantly is surprising but consistent with a model for melt extraction by *Schutt and Lesher* [2006].

Seth Stein

One of the best exposures of the Midcontinent Rift's 1.1-billion-year-old volcanic rocks is in Interstate Park, along the border between Minnesota and Wisconsin, where the St. Croix River cuts through a series of lava flows.

Moreover, mantle flows or oriented magma bodies usually make seismic wave speeds vary depending on the direction the waves travel, so waves tend to go faster along currently extending rifts than across them. However, *Ola et al.* [2016] find no such anisotropy below the MCR, perhaps because much of the volcanism occurred after extension ended.

Current and future studies combining petrology, geochemistry, geochronology, paleomagnetism, plate motions, and magnetotellurics will continue to explore what these surprises mean for the evolution of the rift.

Did a Hot Spot Supply the Excess Magma?

The MCR is an extraordinary feature that arose from an unusual combination of a continental rift and an LIP, illustrating that over a billion years of Earth history, even unlikely events can happen. Rifting can be classified into two types: "passive" rifting in which forces pull the lithosphere in opposite directions, extending it [*Sengor and Burke*, 1978], and "active" rifting, where a mantle plume or hot spot thermally uplifts and stretches the crust above it [e.g., *Nicholson et al.*, 1997]. For the MCR, we suspect that the rifting continent by chance overrode a plume or a region of anomalously hot upper mantle, so both active and passive rifting may have been at play.

Modeling implies that the MCR's magma volume cannot have been generated by passive upwelling beneath an extending rift

Initial modeling [*Moucha et al.,* 2013] implies that the MCR's magma volume cannot have been generated by passive upwelling beneath an extending rift, even though the Precambrian mantle was hotter than today's. *Bowles-Martinez and Schultz* [2015] find a highly conductive anomaly below western Lake Superior and northwestern Wisconsin, extending to depths below 200 kilometers, that may have been formed by a mantle plume and somehow persisted. A question currently being discussed involves how the magma source operated over a long period of rapid plate motion [*Swanson-Hysell et al.,* 2014].

MCR Failure

The MCR was previously thought to have failed—stopped extending—because of regional compression associated with the Grenville orogeny [*Cannon*, 1994]. However, new age dating shows that most of the compression recorded by reverse faulting occurred long after extension and volcanism ended. Thus the MCR's failure was not due to Grenville compression [*Malone et al.,* 2016]. Instead, it stopped spreading much earlier, once seafloor spreading between Amazonia and Laurentia was fully established.

Insights into Other Rifts and Continental Margins

The MCR results help place other rifts worldwide in their evolutionary sequence via "comparative riftology"—comparing rifts at different stages in their evolution. Today's East African Rift looks like what we envision for the MCR during rifting—a gravity low, low velocities due to

the high temperatures, and thin crust below the extending arms. The Southern Oklahoma Aulacogen, a failed rift that opened in the Cambrian breakup of Rodinia and was inverted in the late Paleozoic, appears similar to today's MCR, with a gravity high due to the igneous rocks filling the rift.

By analogy, failed rifts similar to the MCR will have thick crust even if they have not been inverted, and inverted ones will have the thickest crust. Similarly, the gravity anomaly should change from a low to become progressively more positive as the rift fails and is later inverted.

The MCR has many features similar to those observed at volcanic passive continental margins. Volcanic margins arise where continental rifting is associated with large-scale melting that gives rise to thick igneous crust. Hence the MCR shows what a passive margin looked like in its early stages.

MCR's Legacy Showcases Geology's Effect on Culture

The MCR highlights geoheritage: geology's role in an area's culture and growth [*S. Stein et al.,* 2015]. Lake Superior and the surrounding spectacular scenery in national, state, and provincial parks are underlain by the MCR. The lake lies above the rift because soft sedimentary rocks within the MCR were easier for ice age glaciers to erode than the volcanic rocks. Thus the rift provided the region's first transportation system—Native Americans and Europeans used the lake to import and export trade goods. The lake remains an economic engine and tourist attraction.

Also, the MCR's mineral deposits shaped the region's settlement and growth. Water flowing through the volcanic rocks dissolved copper and deposited it in concentrations that became sources of valuable ore in many places around Lake Superior. For at least the past 7000 years, Native Americans have mined copper and traded it as far south as Illinois. The discovery of commercially viable copper deposits during the 1840s led to a mining boom that shaped the area's economy.

More information for the public, park interpreters, informal educators, and teachers can be found on websites hosted by Michigan Technological University (http://bit.ly/mtu-mcr) and Northwestern University (http://bit.ly/nwu-mcr).

The MCR is a place where visitors can interact with geological features more than 1 billion years old. Its evolution—from extensional beginnings to rift failure, from ice age glaciers scouring it to lake infill, from ancient copper miners to modern boaters enjoying a lazy summer day—shows how geology weaves the fabric not only of our continents but also of our lives.

Acknowledgments

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Author Information

Seth Stein, Northwestern University, Evanston, Ill.; email: seth@earth.northwestern.edu; **Carol Stein,** University of Illinois at Chicago; **Jonas Kley,** Georg-August-Universität Göttingen, Göttingen, Germany; **Randy Keller,** University of Oklahoma, Norman; **Miguel Merino,** Chevron Corporation, Houston, Texas; **Emily Wolin,** Northwestern University, Evanston, Ill.; **Douglas Wiens, Michael E. Wysession, Ghassan Al-Equabi,** and **Weisen Shen,** Washington University, St. Louis, Mo.; **Andrew Frederiksen,** University of Manitoba, Winnipeg, Man., Canada; **Fiona Darbyshire,** Université du Québec à Montréal, Montreal, Que., Canada; **Donna Jurdy,** Northwestern University, Evanston, Ill.; **Greg Waite, William Rose,** and **Erika Vye,** Michigan Technological University, Houghton; **Tyrone Rooney,** Michigan State University, East Lansing; **Robert Moucha,** Syracuse University, Syracuse, N.Y.; and **Eric Brown,** Aarhus University, Aarhus, Denmark


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Augmented Reality Turns a Sandbox into a Geoscience Lesson

By Sarah Reed, Sherry Hsi, Oliver Kreylos, M. Burak Yikilmaz, Louise H. Kellogg, S. Geoffrey Schladow, Heather Segale, and Lindsay Chan

Superimposing responsive digital effects onto sand in a sandbox places educators, students, and policy makers in an augmented reality, offering a hands-on way to explore geoscience processes.

Lauren Lipuma/AGU

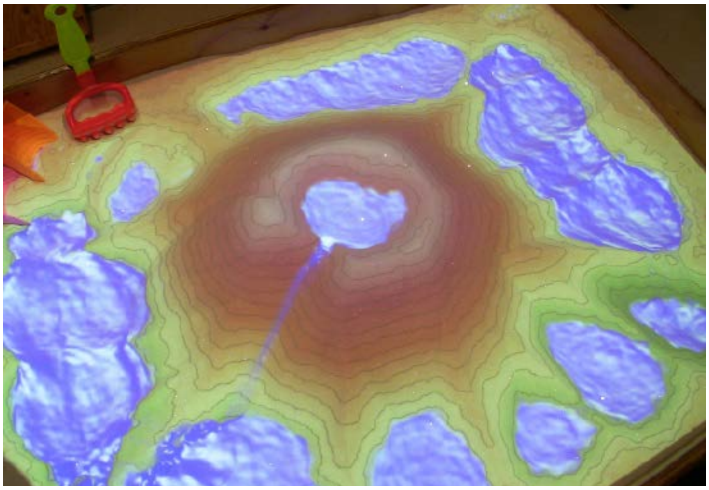
A student uses a rake to scrape sand in a 4- by 3-foot box, forming hills and valleys. Overhead, a Microsoft Kinect camera automatically gauges the distance to the sand and projects contour lines and colors onto the scene—cool colors for depressions, warm colors for peaks.

As the student pushes sand around into peaks, the colors swirl and dance, forming green and orange islands in a sea of blue. She hovers her palm over a mountain, and virtual rain pours down, slicking over cliffs and plunging into the blue.

The student is using a specially designed augmented reality (AR) sandbox, developed by the LakeViz3D project, a collaboration that seeks to foster public awareness and stewardship of freshwater ecosystems. Unlike virtual reality, which immerses the user in a digitally generated environment, AR superimposes visual, audio, and other digital effects onto a real-world scene or display that users can manipulate.

What results is an interactive tool for geoscience education and science communication. One of the challenges in learning Earth

Students at Howard University Middle School of Mathematics and Science in Washington, D. C., reshape sand in their school's Augmented Reality (AR) Sandbox. Above, a projector maps contour lines and colors indicating elevation—these continually adjust to the changing landscapes that students build.



Oliver Kreylos

Overhead view of the Shaping Our Worlds Augmented Reality (AR) Sandbox showing contour lines and virtual water projected onto sand "landforms." We chose a color mapping similar to that used in atlases (white for peaks and high elevations, red/brown for upper slopes, and green for lower slopes) and specific contour spacing for the default visualization to help users understand how elevation changes relate to hydrologic processes.

science is visualizing processes that occur over large spatial and temporal scales. However, with the Shaping Our Worlds AR Sandbox, many slow, large, and complex Earth processes can become more apparent and tangible.

What Is the AR Sandbox?

The AR Sandbox combines the power of exploration for advancing learning [*Singer et al.*, 2006] via a kinesthetic experience in which users create topographic models by shaping sand with geoscience-relevant digital imagery [*Reed et al.*, 2014].

The AR Sandbox uses a computer projector and a motion-sensing input device (e.g., a Microsoft Kinect three-dimensional (3-D) camera) mounted above a box of sand. The user shapes the sand in the box, and the camera detects the distance to the sand below. A 3-D model of the sand surface is used to project contour lines and a color-coded elevation map representing the corresponding topography onto the sand's surface. As users move the sand, the camera perceives the changes, and the projected colors and contour lines change accordingly.

When the camera senses an object (such as a hand) at a specified height above the sand surface, virtual rain appears below the object as a blue, dynamically changing texture on the sand. A flow simulation model moves the water across the landscape in accordance with the laws of motion and the boundary conditions provided by the shape of the sand. The virtual water slowly disappears as the simulation computes its infiltration into the soil, or it can be drained rapidly with a push of a physical button or computer key.

History of Development

The prototype of the AR Sandbox was developed at the Keck Center for Active Visualization in Earth Science (KeckCAVES) at the University of California (UC), Davis. This project was originally inspired by the SandyStation, developed by researchers working in the Czech Republic (see http://en.sandystation.cz).

The AR Sandbox prototype became an interactive public exhibit for science education as part of the multidisciplinary National Science Foundation (NSF)–funded LakeViz3D. This collaboration of scientists, science educators, evaluators, museum professionals, and media developers created 3-D visualizations to help improve public understanding and stewardship of freshwater ecosystems.

The first four AR Sandboxes were built at the science center partners of LakeViz3D: KeckCAVES; the Lawrence Hall of Science in Berkeley, Calif.; Tahoe Environmental Research Center in Incline Village, Nev.; and Ecology, Culture, History, and Opportunities (ECHO), Leahy Center for Lake Champlain in Burlington, Vt.

The software that produces the visualization is created using an open-source virtual reality development tool kit for 3-D graphics applications (VRUI), also developed at KeckCAVES. The flow visualization is based on the Saint-Venant shallow-water equations, a depth-integrated version of the Navier-Stokes fluid flow equations [*Kurganov and Petrova*, 2007].

Strong Engagement and Adaptable Earth Science Learning

The AR Sandbox was initially launched in museum settings in 2012, and it has since been adapted for use in more than 150 universities, research centers, conferences, government organizations, and schools around the world. Applications span a wide variety of Earth science topics and learning environments.

People, regardless of age or background, like to learn by exploring. The tangible interaction and kinds of inquiry provided by the AR Sandbox provide a high level of engagement. Users are initially drawn in by the vibrant colors and water flow visualization. When they recognize that their

Watch a video of the AR Sandbox in action at http://bit.ly/EOS_ARSandbox

actions can not only reshape the sand but also control the visualizations, they are truly hooked.

In the sandboxes at the LakeViz3D institutions, users often stay at the sandbox for more than 20 minutes (and sometimes more than an hour), far exceeding common dwell times at single exhibits. In addition, users are frequently observed working together on tasks they have set for themselves, especially building specific landscapes with the sand [*Audience Viewpoints Consulting*, 2014].

Educators can demonstrate a wide range of Earth science concepts interactively. For instance, they can show—and encourage students to build—the varied landforms found on Earth's surface and illustrate how they were created by a variety of processes such as flooding, erosion, tectonics, and glaciation.

The U.S. Geological Survey Cascades Volcano Observatory reports that "the sandbox is a mesmerizing storytelling device." Staff there use the sandbox to explore with visitors how composite volcanoes like Mount St. Helens are built, what happened during the 1980 eruption, and how lahars can travel far downstream of a volcano.

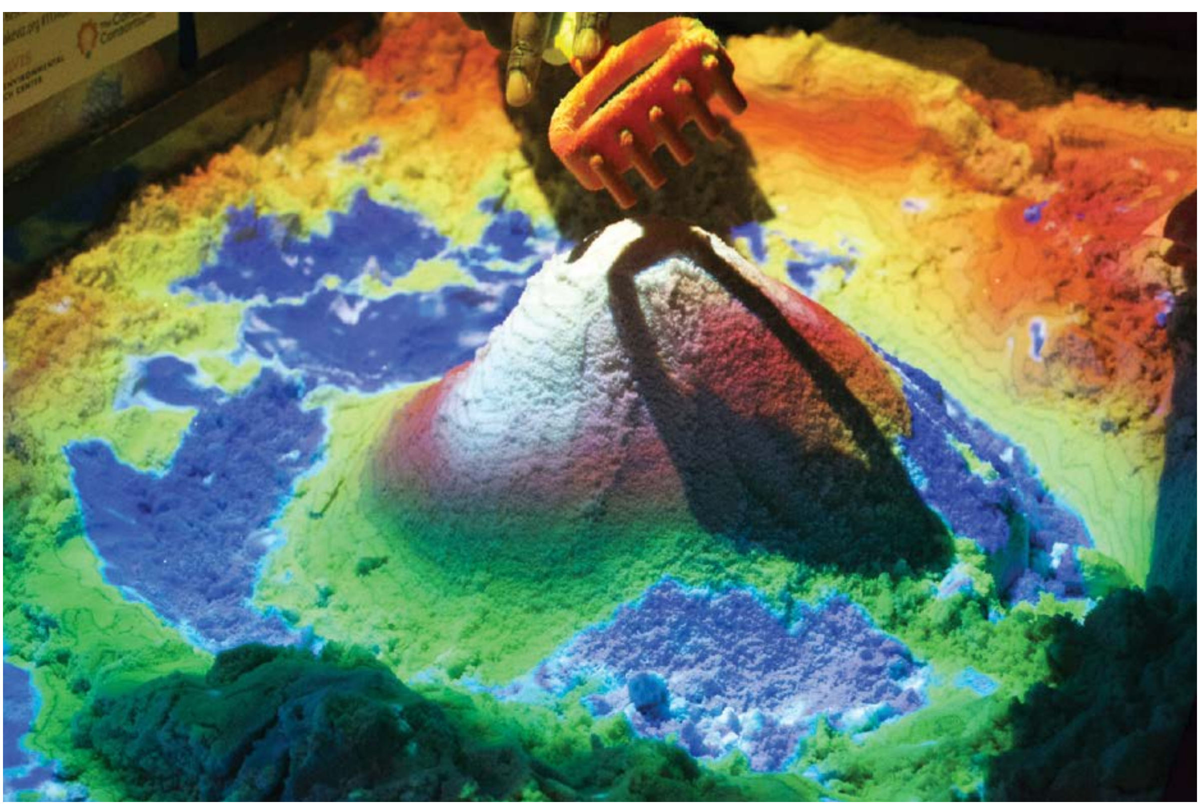
Instructors have used the sandbox successfully to teach university-level students about topographic maps, hydrology, and geomorphology. At UC Davis, students in upper division structural geology courses use the AR Sandbox to visualize subsurface structures before they go out into the field.

Faculty of East Carolina University (ECU) in Greenville, N.C., report that the AR Sandbox helps students in physical geology laboratories interpret contour lines and visualize the 3-D landscape depicted as lines on a topographic map, concepts that students find challenging. In addition, ECU students model, predict, and then explore whether water can move naturally on the surface from one drainage basin to an adjacent basin [*Woods et al.*, 2015].

At the University of Redlands in Redlands, Calif., instructors of geology and natural disasters courses found that the sandbox reduces barriers to spatial learning and helps students develop an intuition for understanding topography and its applications [*Jenkins et al.*, 2014].

Tyler Esser via GMT, GNU LGPL3+

More than 150 AR Sandboxes have been developed following the original LakeViz3D model. These include sandboxes at schools, universities, research centers, government organizations, museums, and science centers. The AR Sandbox is being used to investigate and teach a wide array of topics, including geology, soil science, hydrology, energy and mineral exploration, forestry, seismology, military operations, coastal engineering, regional planning, and disaster preparedness.



Lauren Lipuma/AGU

A student at Howard University Middle School of Mathematics and Science prepares to flatten a mountain within the school's AR Sandbox.

On the basis of these positive results, we propose that AR Sandboxes be more widely instituted in university geoscience education.

The AR Sandbox as a Tool for Science Communication and Research

The engagement and learning benefits of the sandbox can also help scientists communicate their research to policy makers, funding agencies, and the public.

Recently, the AR Sandbox was featured at this year's annual meeting of the American Association for the Advancement of Science. One was also presented in the NSF booth at the USA Science and Engineering Festival in Washington, D. C., attended by more than 300,000 members of the public, and at the White House Water Summit. That particular AR Sandbox was then installed in a sixth-grade classroom at the Middle School of Mathematics and Science on the nearby Howard University campus.

At these gatherings, the visualizations provided by an AR Sandbox served as a powerful outreach and communication tool to engage politicians, collaborators, students, and funders in deeper conversations around large data sets involving local and global systems of change. For example, land management and planning agencies can test environmental change scenarios in an AR Sandbox to inform decisions related to natural disaster planning.

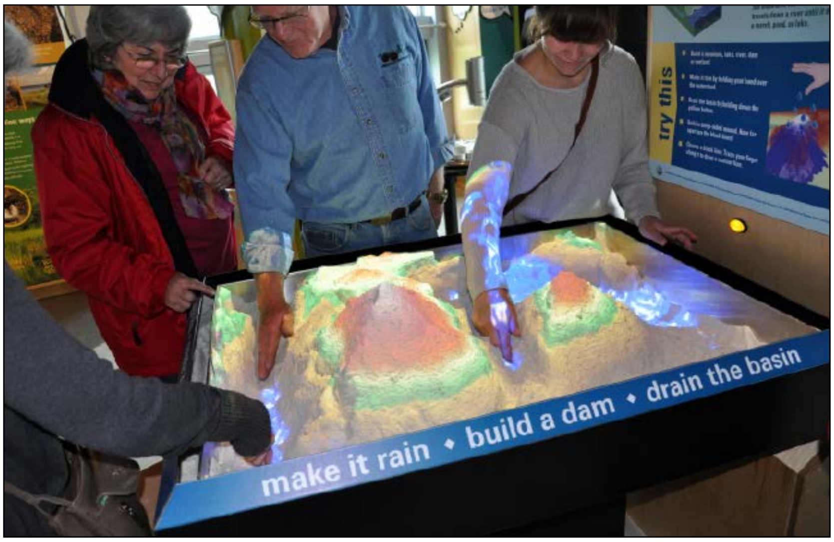
In fact, researchers at Newcastle University in Newcastle upon Tyne, U.K., are using an AR Sandbox to study and communicate flood risk. Educators at the Zephyr Education Foundation in Falmouth, Mass., use the sandbox to build topographic models of Boston, with which they explore sea level rise and storm surge scenarios. Earth science researchers can also use AR Sandboxes to project a variety of Earth observation data (e.g., satellite images, vegetation indices, solar radiation) onto 3-D landscape models to better visualize and understand how spatial patterns of environmental data relate to topography.

Building the Next-Generation Learning Sandbox

Developers, scientists, and educators are invited to further enhance the capabilities of the sandbox and extend the modeling software. The 3-D software used to create the AR Sandbox is open-source and freely available online, together with the sandbox blueprints, a facilitator's guide (support and ideas for teaching with the sandbox), and a public forum for help troubleshooting sandbox issues or to post questions and suggestions (see https://arsandbox.org).

We are excited to see the many innovative AR Sandbox applications and modifications that have emerged. We hope that others are inspired to explore the sandbox and expand its application in Earth science education, policy, and research.

To find an AR Sandbox near you, visit http://bit.ly/ARSandboxMap.



ECHO, Leahy Center for Lake Champlain

Visitors explore the AR Sandbox exhibit at the Ecology, Culture, History, and Opportunities (ECHO), Leahy Center for Lake Champlain, a science center and lake aquarium in Burlington, Vt. Here visitors use the sandbox to learn about how humans interact with and influence watersheds. Sandbox users can build and breach dams and think about where people build cities and what risks building in different places poses to humans and the environment. Users can also explore the possible effects of drought and its environmental effects using the exhibit's "drain" button, which removes all the virtual water.

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Author Information

Sarah Reed, The Lawrence Hall of Science, University of California, Berkeley; email: s_reed@berkeley.edu; **Sherry Hsi,** The Concord Consortium, Emeryville, Calif.; **Oliver Kreylos, M. Burak Yikilmaz,** and **Louise H. Kellogg,** Department of Earth and Planetary Sciences, University of California, Davis; **S. Geoffrey Schladow,** Tahoe Environmental Research Center, University of California, Davis; **Heather Segale,** Tahoe Environmental Research Center, University of California, Davis, Incline Village, Nev.; and **Lindsay Chan,** Department of Earth and Planetary Sciences, University of California, Davis

Closing the Air Quality Data Gap in the Developing World

Air pollution in Ulaanbaatar, Mongolia, can make it look as if the city is constantly covered by fog or smoke. A lack of local air quality data made it difficult to quantify health effects or gain political traction to improve the city's air quality.

A chance encounter with a photograph sparked a new international air quality data resource, the latest recipient of a Thriving Earth Exchange grant from AGU. Christa Hasenkopf, a recent Ph.D., worked as an atmospheric research scientist in Boulder, Colo. She and her husband, Joe Flasher, an astrophysicist and software developer, knew that they wanted to work internationally after Hasenkopf graduated.

They didn't know exactly what form their work would take, but social relevance was important to both of them. Hasenkopf had worked with Teach for America in Baltimore, Md., and Flasher was interested in applying his expertise in open data and technology to solve global problems.

One day, Hasenkopf was speaking with a researcher colleague who had recently spent time in Mongolia when the colleague shared a photo showing the view from his hotel window in Ulaanbaatar, Mongolia's capital. The air pollution was so severe that it was clearly visible in the photo.

Neither Hasenkopf nor Flasher had expertise in air pollution specifically, although Hasenkopf had some relevant knowledge from studying particulate matter on Saturn's moon Titan. The photo cinched the location for their planned international move—it inspired the couple to move to Ulaanbaatar and learn more.

They quickly realized that despite the obviously severe pollution, residents and decision makers had virtually no local data on air quality. They did, however, have the evidence of their own observations. Living in highly polluted areas can cause respiratory and cardiovascular disease, but without data, it would be difficult to document the devastating health effects of Mongolia's pollution or to get traction to make things better.

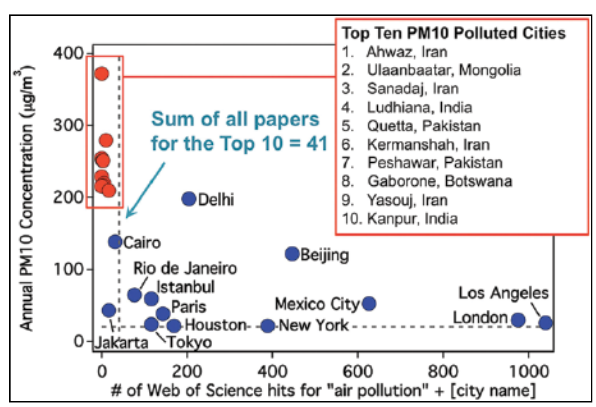
Drawing on Hasenkopf's atmospheric science knowledge and Flasher's software development skills, the couple collaborated with the local science community to build Mongolia's first social media–based air quality data-sharing platform. It wasn't long before the platform elevated the conversation about air pollution in Mongolia. National news outlets covered the project, and the team was invited to present research to the Mongolian Parliament, the U.S. Embassy, and the Canadian Embassy.

The couple, empowered by the success of that first project, decided to expand their focus from Mongolia to the entire developing world. According to the World Health Organization, poor air quality is responsible for one in eight deaths around the world, and 90% of those deaths occur in developing countries. Yet the developing world, where the problem is most acute, is exactly where data are scarcest. To address this gap, the team created OpenAQ (https://openaq.org), the world's first free, open, real-time, international air quality data hub.

OpenAQ was recently awarded a $15,000 Sharing Solutions grant from AGU's Thriving Earth Exchange (http://thrivingearthexchange.org) and Amazon Web Services, which allows the team to use Amazon's cloud-computing services to store and share data and code. Winning the award "is a huge opportunity to scale up our platform, get more data, and share it out," said Hasenkopf.

Many developing countries and localities do collect air quality data, but typically they are not archived, standardized, or aggregated. The OpenAQ platform is designed to harvest and bring together real-time data from the thousands of official, publicly available data sources around the world, both large and small. The data are then captured and archived to make them available for research.

The strength of the OpenAQ platform lies in its open-access model and its open-source



Some of the world's most polluted cities are also those with the least air quality data and research. (PM10 refers to particulate matter 10 micrometers or less in diameter.)

code. The data are freely available for any scientist, journalist, educator, or policy maker to access, and any software developer can create apps that use these data.

Despite the obviously severe pollution in Mongolia, residents and decision makers had virtually no local data on air quality.

In addition to providing a platform for data sharing, OpenAQ also hosts workshops and creates tools to guide users. The ultimate goal of all this is to inspire scientists, activists, and engineers to create data visualizations, analytics, and software that can be used to influence government policy to protect public health. OpenAQ tracks such projects on its blog (https://medium.com/@openaq) so that involved researchers, developers, and community members can learn from one another. Hasenkopf is confident that OpenAQ could also add value to international projects like the World Health Organization's Outdoor Air Pollution Database and the Global Burden of Disease study.

"Our main goal, in addition to aggregating [these] data, is to get people involved in the platform as much as they want to be," said Hasenkopf. "There is always an open invitation for people to reach out to us."

"This is a community effort with some fantastic, wonderful folks, from the U.S. to Spain to Rwanda to Mongolia, who have been essential to the platform," she added.

To date, the data aggregated by OpenAQ have been accessed from 674 cities in 88 countries. The team hopes that the platform will provide a sustainable, community-driven environment for concerned individuals to come together, use data, and find solutions for some of today's most pressing environmental health issues.

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By **Kathleen Pierce,** Freelance Science Communicator/Contributing Writer for Creative Science Writing and the Thriving Earth Exchange; email: kathpierce@gmail.com

Charting the Future for AGU's Meetings Program

Ebbe Roe Yovino-Smith/Gary Wagner Photography

Attendees of the 2015 AGU Fall Meeting in San Francisco stride through the hallways and talk with colleagues between scientific sessions.

For 5 decades, the AGU Fall Meeting has been a place where members of the Earth and space science community come to learn more about the latest research, to make connections with potential collaborators, to reconnect with colleagues, and to advance their careers. In the past decade, attendance has grown rapidly, testament to the meeting's value within the scientific community. In addition, Joint Assembly, the Meeting of the Americas, and meetings with partner organizations such as the Japan Geoscience Union have provided similar experiences on the international stage. Also, ground-breaking research has emerged from the more than 50 Chapman Conferences AGU has hosted since 2007.

Today, however, growth in attendance at the Fall Meeting has begun to level off (see Figure 1), and we are increasingly hearing concerns that the meeting is too big to be useful but too important to be missed. What's more, although other meetings in AGU's portfolio, such as the Chapman Conferences, receive high marks for their scientific quality and attendee experience, their lack of integration with the rest of the Union's meetings program limits AGU's ability to have a greater impact.

Changing Methods of Communication and Collaboration

Because AGU has already conducted extensive research with attendees, we know that they rely on our meetings as opportunities to network and collaborate as much as to present their research. We also know that their communications and collaboration methods are changing—and changing quickly. Whether researchers document their work on Tumblr, present via Periscope, collect data via apps, or find potential collaborators on Twitter, it's clear that they no longer regard the poster hall, session room, and networking reception as their only (or even primary) way to advance science.

Despite these changes, AGU's meetings program has remained largely the same. Meeting formats haven't evolved at the same pace as people's behavior and expectations, and our portfolio of meetings could be more effective at facilitating our attendees' ability to advance their science and careers. This disconnect limits AGU's potential for growth and

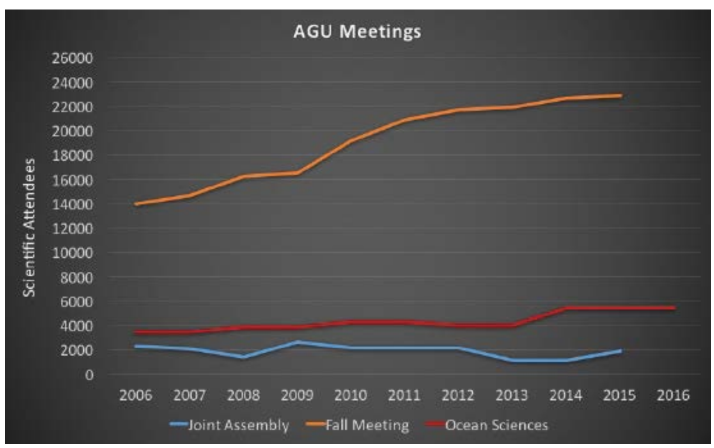
sustainability, as well as our ability to advance the Union’s mission to “promote discovery in Earth and space science for the benefit of humanity.”

A New Vision for AGU’s Meetings Program

With these circumstances in mind, AGU undertook in 2014 a strategic review of our meetings program. Following the results of that study, President Margaret Leinen formed the Meetings Strategy Task Force to develop a vision for how AGU’s meetings program can better meet the needs of our members.

This goal likely sounds familiar, given that in recent years AGU has taken similar steps for our governance structure and publications program. In both cases, groups were formed to study the landscape in which AGU operates, to solicit feedback from stakeholder groups, and to develop short- and long-term strategies to improve the success of each program and its ability to meet the needs of the Earth and space science community.

The Meetings Strategy Task Force was convened early in 2016 and has met several times, both virtually and in person, to begin drafting the strategy to present to the AGU Board and Council for their comments in September 2016. The final strategy will go to the Board for approval in December 2016, to be followed by creation of a multifaceted implementation plan starting in early 2017.



AGU

Fig. 1. After a period of rapid growth, scientific attendance at AGU’s Fall Meeting has increased more slowly in recent years. Among other AGU-sponsored meetings, Ocean Sciences has grown modestly while the Joint Assembly has remained roughly unchanged.

Key Areas for Development

Already, the task force has begun to analyze the strategic review findings from 2014, as well as feedback from AGU leadership, numerous years’ worth of meeting surveys, AGU member surveys, and other data and member input. During this process, task force members have identified several keys areas for development, including supporting the growth and advancement of transdisciplinary science, facilitating the identification of rapidly emerging scientific topics, engaging attendees outside of the meeting itself, collecting and analyzing outcomes, and optimizing the meeting experience for each individual.

They have also considered issues such as how AGU can enhance its connections to the public and ensure that its meetings program has a broader impact in society, how we can better integrate Earth and space science content—for instance, by linking the meetings program to AGU publications—and how we can improve networking within and among groups ranging from single- or cross-disciplinary communities to students and the established scientists who are willing to serve as their mentors.

Feedback from AGU Members and Meeting Attendees

The task force recognizes that feedback from AGU members and attendees is vitally important to the success of this effort. Although task force members have already reviewed a great deal of AGU member feedback to inform development of the draft strategy, they are aware of the importance of meetings to AGU members and will be seeking additional insight. Once the draft strategy has been written, AGU will look to its members to help envision the strategy’s implementation and how the strategy will influence the growth and transformation of AGU’s meetings portfolio. Examples of the types of questions the task force might ask at that time include the following:

- *What should change about AGU’s meetings to improve the attendee experience?* Our reinvention of the meetings experience goes beyond operational issues, such as larger rooms and shorter beer lines. We want to focus on transformational ideas. Here is a taste of what we mean: Imagine poster sessions with touchscreen monitors to display animations and that allow attendees to zoom in on elements of graphs, eliminating the need for printed posters and allowing for interactivity even when the presenter isn’t there.
- *What types of meetings should AGU offer to better facilitate our members’ science?* Our current meetings portfolio includes the broad and very large Fall Meeting, several smaller but still fairly broad meetings (such as Ocean Sciences), and the much smaller and more targeted Chapman Conferences. Although this portfolio includes larger and more diverse meetings than many other science societies offer, given the changing nature of our science, does it really support the work AGU members are currently involved in? For example, would small, targeted workshops allow us to better support the kind of collaboration our attendees need?
- *Might new meeting formats, such as transdisciplinary meetings or open space meetings, increase AGU’s impact on society and emerging sciences?* Could AGU be more proactive in building relationships and working with societies of engineers, public policy specialists, economists, social scientists, or practitioners of other disciplines to develop transdisciplinary meetings, such as catastrophe risk modeling? Would this enable AGU to do more to inform society? And if we embraced the concept of open space meetings—events where only the date and topic are decided in advance and the attendees work together to develop the agenda and outcomes—could we be more effective in addressing pressing needs in emerging areas of science?

Experimentation to Begin Soon

We look forward to keeping you up to date on the progress of this important effort and, when the time comes, seeking your input to help us imagine what the scientific meeting of the future will look like.

Those attending the Fall Meeting in 2016 will see our preliminary efforts to experiment with new formats and opportunities. When the meeting travels to New Orleans in 2017 and Washington, D. C., in 2018, the change of venue will give us an opportunity to experiment even more. The possibilities for AGU’s meetings program are endless, and we want our members and attendees to help us chart the future.

By **Rick Murnane,** Meetings Committee Chair, AGU, and AGU Council Member; email: agumeetingschair@agu.org

RESEARCH SPOTLIGHT

Revising the Displacement History of New Zealand's Alpine Fault

Tristan Schmurr

A view of Aoraki (Mount Cook) in the Southern Alps of New Zealand, still on the rise due to the Alpine Fault.

In New Zealand, the boundary between the Pacific and Australian plates is defined by the Alpine Fault, a major strike-slip feature with a small horizontal component of compression that is actively raising the Southern Alps mountain range along the South Island's western edge. According to the prevailing view, the Alpine Fault has accommodated about 450 kilometers of right-lateral displacement during the past 40 million years.

Because this offset accounts for less than 60% of the long-term relative motion between these plates, previous studies have assumed that rotation and displacement on other faults across a 300-kilometer-wide zone have accommodated the difference. However, *Lamb et al.* question this view and present an alternative view of long-term deformation in this area.

On the basis of a reinterpretation of structural and paleomagnetic data, the team suggests that previous displacement estimates rely on incorrect assumptions about the orientation of a series of terranes that are offset along the Alpine Fault. Earlier studies assumed that these terranes were contiguous across the fault in the Eocene, when the modern plate boundary developed. The authors conducted a reanalysis of paleomagnetic data from the sediments covering these terranes, ranging from 36 million to 15 million years in age, and found that there was insufficient deformation during that period to account for their present locations.

The results instead suggest that the total displacement along the Alpine Fault has exceeded 700 kilometers in the past 25 million years. This offset, the researchers argue, has reversed roughly 225 kilometers of left-lateral motion that occurred during the Late Cretaceous. This early left-lateral displacement was linked to rifting between East and West Antarctica during the breakup of Gondwana.

To accomplish this hefty displacement, the Alpine Fault has maintained an average rate of slip comparable to its present-day rate (about 30 millimeters per year) over the past 25 million years—a rate that is both faster and has persisted longer than those of other major continental strike-slip boundaries.

The revised history indicates that a narrow, 10-kilometer-wide zone straddling the fault has accommodated more than 94% of the relative plate motion, suggesting that deformation at continental plate boundaries does not need to occur across broad distributed zones, as has been widely assumed. Instead, the zone more closely resembles oceanic plate boundaries, where relative plate motion is accommodated by narrow transform faults with lengthy histories spanning tens of millions to hundreds of millions of years. (*Geochemistry, Geophysics, Geosystems,* doi:10.1002/2015GC006225, 2016)

—Terri Cook, Freelance Writer

Your Phone, Tablet, and Computer Screens Aren't Safe from Hackers

Picture this scene: A hacker takes a seat in a crowded cafe, latte in hand, and casually pulls out her laptop. With a discreet sideways glance, she eyes her target at the table next to her, blithely tapping away on a tablet. He's not on Wi-Fi, but that doesn't matter. Her laptop is equipped with special equipment to detect the electromagnetic disturbances emanating from the tablet screen itself. She carefully shifts her laptop on the table, it picks up and processes the signal, and—voilà!—his tablet screen comes into view on hers, its images plucked out of the air.

iStock.com/Rostislav_Sedlacek

Electronic gadgets are becoming targets for hackers, thanks to accidental antennae on every screen.

This isn't just spy movie gadget magic. In recent years, researchers have demonstrated this exploit, successfully decoding the leaked signals to recover an on-screen image. In a new paper, *Hayashi* highlights this security threat and how electronics manufacturers can take steps to secure our screens.

This hack is possible because the internals of every computing device we own give off electromagnetic radiation. It leaks from the cables and circuitry that carry the display signal from the processor to the screen, and it's even emitted by the screen pixels themselves. These cables and circuitry become accidental antennas that transmit the display signal into our surroundings—one that a would-be hacker could tune in to.

The reproduced image isn't always perfect; the hack works best with mostly static images and high-contrast changes. But that's good enough to take advantage of mobile devices, whose on-screen keys light up when they're touched, making it possible to capture passwords and other sensitive input. The author notes that as receiver technology gets better and cheaper, the threat to our screens will only grow.

To combat these attacks, users can take some measures to shield their devices: For example, placing a see-through conductive film over the display can reduce screen leakage. But the author also says that manufacturers, which so far have focused on protecting our data, must now also consider how to design devices with secure screens. Possible countermeasures include passive solutions like internal shielding and ensuring that components don't act like antennas. But they may also extend to active solutions like embedding a piece of circuitry to scramble the signal. (*Radio Science,* doi:10.1002/2016RS006034, 2016) **—Mark Zastrow, Freelance Writer**

Insights into Long-Standing Bias in Cloud Property Retrieval

Clouds play an incredibly important role in shaping the Earth's climate, both reflecting solar radiation back out to space and acting like an insulating blanket, trapping heat near the surface. The net warming or cooling effect depends on several properties, including cloud optical thickness and droplet size. But unlike other facets of climate science, clouds are ethereal and transient, making them difficult to model despite their importance.

One of the most commonly used methods for analyzing cloud properties is known as the bispectral method, which measures the reflectance of two different wavelengths of light to glean information about a cloud's optical thickness and droplet radius. These measurements, usually gathered by orbiting satellites, rely on breaking an image down into pixels and performing a pixel-by-pixel analysis.

Although useful, this sort of approximation can also lead to significant biases because it ignores subpixel variation and doesn't account for the fact that each pixel is continuous with—and thus constantly influencing—its neighbors. This problem can be exacerbated because many current analyses treat optical thickness and droplet radius as two independent, noninteracting variables. In reality, they influence each other.

In an effort to understand and quantify how these subpixel variations can bias the bispectral method, *Zhang et al.* developed a new mathematical framework that uses a Taylor expansion to account for the fact that droplet radius and optical thickness variables are mutually dependent. The framework allows researchers to estimate how the two variables change from one application of the bispectral method to the next, especially when using different satellites, which often have different pixel resolutions.

The team then applied their framework to real-world data acquired from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS), as well as data from a synthetic cloud field created using a large-eddy simulation model called DHARMA. MODIS collects data at several different spatial resolutions, i.e., different pixel sizes. This allowed the researchers to explore whether their framework could predict the variations observed in the reported optical densities and droplet radii for the different resolutions. The team reports that their framework was quite useful in predicting the biases caused by subpixel variability in both the large-eddy simulation and real-world MODIS data.

The researchers suggest that their mathematical framework could be useful for understanding the statistical differences observed at different spatial resolutions when using the bispectral method to resolve cloud properties, thus providing future researchers with more accurate tools to analyze our planet's clouds and their impact on climate. (*Journal of Geophysical Research: Atmospheres,* doi:10.1002/2016JD024837, 2016) **—David Shultz, Freelance Writer**

ATMOSPHERIC SCIENCES

Post Doctoral Fellowship in Simulation of Wind Climates

Description

Applications are sought for a Post Doc to participate in a project designed to (i) quantify aspects of wind climates of relevance to wind energy, (ii) assess causes of intra-annual to intra-decadal variability in wind climates and (ii) diagnose where and how wind conditions may change over time. This project is a collaboration between professors at Cornell University, scientists at a national laboratory (PNNL) and in private industry, and the selected applicant will have the opportunity to work closely with all three partners.

Qualifications

The selected applicant will lead the numerical modeling using WRF and a global variable resolution model, and must hold a Ph.D. in atmospheric science, engineering or related subject. Experience with WRF is highly desirable, familiarity with wind engineering or atmospheric modeling using variable resolution models is desirable and familiarity with high-performance computing and programming in Fortran and Matlab is essential.

Term

The preferred start date is 1 November 2016 and the initial appointment will be for 1 year with the possibility of renewal.

Salary

Salary will be commensurate with experience.

How to apply

For full consideration, please send a letter of application, a current curriculum vitae, and the names and contact information of three references to: Professor S.C. Pryor (sp2279@cornell.edu).

Applications will be processed until the position is filled but those received by 15 September 2016 will receive full consideration. Cornell University is an Equal Employment Opportunity/ Affirmative Action Employer and we strongly encourage applications from women and minorities.

Specific responsibilities (and approximate effort allocation):

(45%) Conduct simulations with WRF over North America

(30%) Conduct simulations with MPAS over North America

(5%) Archive model output using best-practice data provenance procedures

(15%) Develop publication-quality research manuscripts

(5%) Other research activities

Postdoctoral Research Scientist

The Department of Applied Physics and Applied Mathematics at The Fu Foundation School of Engineering and Applied Science of Columbia University in the City of New York invites applications for a Postdoctoral Research Scientist position in the area of modeling atmospheric chemistry and aerosol processes over a wide range of oxidation-reduction states and their interactions with the climates of Solar System rocky planets and rocky exoplanets in a three-dimensional general circulation model. This is a full-time position for a 2-year period.

The successful candidate will participate in a groundbreaking NASA research initiative, the Nexus for Exoplanet System Science (NExSS; https://nexss.info), with an interdisciplinary team of scientists from the Goddard Institute for Space Studies (GISS), the Goddard Space Flight Center, Columbia University, and other institutions. The broad goals of the team's research are to address questions about the habitability of the past climates of Earth, Mars, and Venus, to use these insights to assess the habitability of exoplanet climates, and to inform the design of future spacecraft missions for detecting and characterizing habitable exoplanets. The candidate will be expected to perform original research, present the results of the research at scientific meetings, and publish first-author papers in peer-reviewed journals. The candidate will be resident at NASA GISS, located in New York City near the Morningside Campus of Columbia University.

UNIVERSITY OF MARYLAND

University of Maryland, College Park

Director: Earth System Science Interdisciplinary Center (ESSIC)

Leading a significantly expanded vision for ESSIC, the Director will leverage excellence across the campus relevant to the Earth system to build co-operative partnerships with the natural sciences and departments in a wide range of colleges, including but not limited to Agriculture and Natural Resources, Engineering, Public Health, and Public Policy. S/he will be a scientist of the highest quality in any of the disciplines essential to understanding the Earth system and must be a recognized player in the Earth system community, with a strong record of strategic leadership and a demonstrated ability to work collaboratively and successfully, nationally and internationally, inside and beyond academia. ESSIC has 11 academic faculty and 150 research scientists, with an annual research income of approximately $35M, and the Director must have a strong commitment to faculty and staff development. Appointed for a five year (renewable) term reporting to the Dean of the College of Computer, Mathematical and Natural Sciences s/he will also hold a tenured Full Professorship in an appropriate department on the campus. Ph.D. or equivalent required.

Applicants should submit as a SINGLE document a Curriculum Vitae including publications, a description of how their research and their experience qualify them for this position and the names and contact information for five referees. For more detail see http://essic.umd.edu

Please apply at: http://go.umd.edu/essicdir

The position will remain open until filled, but for best consideration applications should be received by December 31, 2016. Inquiries may be sent to: Professor Steve Halperin at shalper@umd.edu.

The University of Maryland, College Park, is an equal opportunity/affirmative action employer.

EARTH AND SPACE SCIENCE INFORMATICS

Assistant Professor in the Energy Cluster at the University of Pennsylvania

As part of a larger investment to create the new Vagelos Institute for Energy Science and Technology, the School of Arts and Sciences at the University of Pennsylvania seeks to add faculty to our newly formed Energy Cluster spanning the natural sciences. We invite applications for a tenure-track assistant professor position in one of the following departments: Biology, Chemistry, Earth and Environmental Science, or Physics & Astronomy. Exceptional senior candidates will also be given consideration. The successful candidate will mount an innovative program of fundamental scientific research that impacts our societal energy challenges, broadly defined, and in doing so will forge collaborative links with other Penn scientists and engineers involved in energy research. Applicants must apply online at http://facultysearches.provost.upenn.edu/postings/937. Required application materials include: curriculum vitae with a list of publications, a research statement that includes the candidate's perspective on how she or he fits into one of the four departments and identifies potential collaborative links with other natural science departments, and a teaching statement. Applicants should also submit the names and contact information for

three individuals who will provide letters of recommendation. Review of applications will start on October 15, 2016 and will continue until the position is filled. The School of Arts and Sciences is strongly committed to Penn's Action Plan for Faculty Diversity and Excellence and to establishing a more diverse faculty (for more information see: http://www.upenn.edu/almanac/volumes/v58/n02/diversity-plan.html). The University of Pennsylvania is an equal opportunity employer. Minorities/Women/Individuals with disabilities/Protected Veterans are encouraged to apply.

HYDROLOGY

Tenure-track faculty position
The Dept. of Geology is seeking a person to teach water resources, physical hydrogeology, chemical hydrogeology, and introductory geology courses as needed starting Fall 2017. Applicant must also involve students in high-quality collaborative research projects. A Ph.D. in geology or a closely related discipline is required at the time of appointment. The department has modern facilities in hydrogeology (including on-campus well nests), geophysics, geochemistry, and sedimentology.

Only online applications are accepted; go to http://uwec.ly/jobopenings to apply. For priority consideration, all application materials must be submitted by October 28, 2016. For a complete position description, call +1-715-836-3732 or visit http://www.uwec.edu/geology/index.htm. UW-Eau Claire is an AA/EEO employer and encourages applications from women and minorities.

INTERDISCIPLINARY

NASA/LIBRARY OF CONGRESS CHAIR IN ASTROBIOLOGY
The John W. Kluge Center at the Library of Congress invites applications from all disciplines for the Baruch S. Blumberg NASA/Library of Congress Chair in Astrobiology, a senior research position in astrobiology and its implications for humanity and society.

The applicant will be in residence at the Library of Congress for up to 12 months and will conduct independent research using the Library's collections that explores the intersection of the science of astrobiology with its humanistic and societal implications. The applicant will also convene related public programs that ensure the subject of astrobiology's role in culture and society receives considered treatment each year in Washington, D.C., and be expected to participate in the intellectual community at the Kluge Center.

The Chair is open to scholars and leading thinkers in the fields of astrobiology, astronomy, planetary science,

Assistant/Associate/Full Professors - Physical and Biological Oceanography, Marine Geophysics/Geology, and Ocean Engineering

South University of Science and Technology of China

The school of oceanography at the South University of Science and Technology of China (SUSTC) invites applications for several tenure-track (or tenured) faculty positions at the ranks of Assistant, Associate, and Full Professor. Applicants must have earned Doctoral degrees in marine geophysics/geology, physical oceanography, biological oceanography, ocean engineering or closely related field. Successful applicants will be expected to establish a robust, externally funded research program and demonstrate a strong commitment to undergraduate and graduate teaching, student mentoring, and professional service. These positions will be open until filled.

SUSTC is a young university at Shenzhen in southern China since 2010 which is set to become a world-leading research university, to lead the higher education reform in China, to serve the needs of innovation-oriented national development and the needs of building Shenzhen into a modern, international and innovative metropolitan. These positions are created with a significant development to establish a vigorous research program in oceanography at SUSTC to serve the national call for China's important role in deep sea research and resource-oriented exploration in the world oceans.

To apply submit a cover letter, complete vitae with list of publications, and three names of references via http://talent.sustc.edu.cn/en/, or to Dr. Y. John Chen, Chair Professor at School of Oceanography, South University of Science and Technology of China, No 1088, Xueyuan Rd., Xili, Nanshan District, Shenzhen, Guangdong, China 518055.

FACULTY POSITION – EARTHQUAKE GEOLOGIST

The Earth Observatory of Singapore and the Asian School of the Environment at Nanyang Technological University seek a geologist whose focus has been the application of modern stratigraphic, geomorphologic and structural methods to understand earthquakes and related phenomena. The successful candidate will have the opportunity to collaborate closely with geochronologists, seismologists, and geodesists at the Observatory. Demonstration of a strong interest in the earthquake geology of Southeast Asia will be essential. The successful applicant will be appointed as both a Principal Investigator within the Observatory and a tenure-track professor in the School. Preference will be given to early- and mid-career applicants.

To apply, please submit the following materials to:
earthquakegeology@ntu.edu.sg

- Cover letter
- Curriculum vitae (To include list of publications and manuscripts in press)
- Statement of research and teaching interests
- A copy of three relevant publications
- Names of 3 references who are familiar with your work and willing to write an evaluation if requested by our search committee.

For more information about the Earth Observatory of Singapore and the Asian School of the Environment, please visit **www.earthobservatory.sg** and **www.ase.ntu.edu.sg**

Applications will be reviewed on a continuing basis throughout the year.

NANYANG TECHNOLOGICAL UNIVERSITY

EARTH OBSERVATORY OF SINGAPORE

Assistant Professor of Earth Sciences

The Ohio State University at Newark is seeking applications for a 9-month, full-time tenure-track position as Assistant Professor of Earth Sciences beginning fall, 2017.

Summary of Duties: Teaching duties include delivering approximately 18 credit hours of instruction per year (semester calendar), primarily in lower-level courses. Research duties include conducting research in accordance with the expectations of the School of Earth Sciences. Service duties encompass contributions to the campus, department, university, and communities in the region.

Qualifications: PhD in earth sciences, a culturally responsive pedagogy appropriate for a racially and ethnically diverse student population, the ability to produce research publishable in scholarly journals, and a documented record of excellence in teaching at the undergraduate level.

Application Procedures: To assure consideration, submit a letter of application, curriculum vitae, three letters of reference (with phone numbers), and a statement of teaching philosophy to: The Ohio State University at Newark, Office of Human Resources, Assistant Professor Earth Sciences, #420687, 1179 University Drive, Newark, OH 43055. To ensure full consideration, application materials must be received by December 5, 2016. Ohio State Newark is an Equal Opportunity/Affirmative Action Employer and is committed to fostering a culturally and intellectually diverse environment and encouraging all members of our learning community to reach their full potential. All qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, national origin, disability status, or protected veteran status.

history of science, philosophy, religion, sociology, anthropology, ethics, literature, the arts, paleontology, Earth and atmospheric sciences, geological sciences or other fields. The Chair may undertake research on a wide range of issues related to how life begins and evolves, or examine the social, religious, ethical, legal, and cultural concerns that arise from researching the origins, evolution, and nature of life in the universe.

The possibilities for research subjects are many. The following are meant to inspire, not to limit creativity: legal issues related to governance of planets and space; ethical implications of cross-contamination; scientific and philosophical definitions of life; conceptions of the origins of life in theistic and non-theistic religions; comparison of the discussion of these issues in multiple nations and cultures; life's collective future—for humans and other life, on Earth and beyond, examining the impacts on life and future evolutionary trajectories that may result from both natural events and human-directed activities; or other subjects that involve astrobiology and its effects on humanity and society.

Proposals should be submitted via the Kluge Center's online application system by close of business on December 1, 2016. Applicants must include a completed application form, a C.V., a complete project proposal, and three references. Applicants should also include as part of their proposal detailed plans and a budget (no more than three pages) for such auxiliary activities as workshops, symposia, or small conferences, explaining how these activities would support the research and/or contribute to any public presentation of the human implications of astrobiology.

The Chair holder will be appointed by the Librarian of Congress on the recommendation of a selection committee consisting of representatives from the academic community jointly selected by NASA and the Library of Congress.

For more information, please visit http://www.loc.gov/loc/kluge/fellowships/NASA-astrobiology.html.

The John W. Kluge Center was established at the Library of Congress in 2000 to foster a mutually enriching relationship between the world of ideas and the world of action, between scholars and political leaders. The Center attracts outstanding scholarly figures to Washington, D.C., facilitates their access to the Library's remarkable collections, and helps them engage in conversation with policymakers and the public. Learn more at: http://www.loc.gov/kluge.

OCEAN SCIENCE

Executive Director of the CLIVAR International Project Office

The First Institute of Oceanography (FIO) and the World Climate Research Programme (WCRP) invite applications for the post of Executive Director of the International CLIVAR (Climate and Ocean - Variability, Predictability, and Change) Project Office.

The goal of CLIVAR is to improve understanding and prediction of ocean-atmosphere interactions and their influence on climate variability and change, to the benefit of society and the environment (http://www.clivar.org). CLIVAR is a core project of the WCRP (http://wcrp-climate.org).

The Executive Director will be responsible for a range of activities including managing the Project Office, participating in relevant meetings, promoting CLIVAR objectives, and seeking sources of additional funding.

Candidates should hold at least an MSc in oceanography, climate or closely relate field. Required skills include a broad knowledge of oceanography and climate science, ability to communicate to a range of stakeholders, and demonstrated team leadership. Excellent written and spoken communication skills in English are essential.

The work place is the First Institute of Oceanography of the State Oceanographic Administration of China, located in Qingdao, China. The position is available from 1st October 2016.

For additional information see Further Details (http://wcrp-climate.org/News-Highlights/2016/Documents/CLIVAR_ED_Further%20details%20final.pdf).

Inquiries about the position may be directed to Mike Sparrow, e-mail: msparrow@wmo.int.

The position will remain open until filled by a suitable candidate. The application must include a covering letter summarizing details of your relevant qualifications and experience, a CV and the names and contact information of three references and should be sent to Ms. Lina Kang (lina.kang@clivar.org).

SEISMOLOGY

Director of the Southern California Earthquake Center and Professor of Earth Sciences, University of Southern California

The Dana and David Dornsife College of Letters, Arts and Sciences of the University of Southern California in Los Angeles, California, seeks a senior earthquake scientist to lead the Southern California Earthquake Center (SCEC) as its director and principal investigator. The appointment will be made at the tenured faculty level (Associate Professor or Professor) in the Department of Earth Sciences (http://dornsife.usc.edu/earth/). The SCEC director will oversee a world-leading program in earthquake system science that currently involves over 1000 earthquake experts at more than 70 universities and research institutions. The successful candidate will have a strong record of federally

funded earthquake research, innovative ideas about the future of earthquake science, and the ability to articulate scientific results to end-users and the general public. She or he will be knowledgeable about the application of advanced computational methods to solve system-level problems, including the use of physics-based methods for earthquake forecasting. Doctoral degree and teaching experience is required.

Applications should include a curriculum vitae, publication list, statement of teaching and research interests, and three names of individuals familiar with the applicant's work who could be contacted for letters of reference. It should also include a vision statement on how, as SCEC director, the applicant would move forward the Center's research program. In order to be considered for this position, applicants are required to submit an electronic USC application through the following link: http://jobs.usc.edu/postings/68664.

Inquiries may be directed to: Chair, Search Committee, c/o Karen Young (kayoung@usc.edu). Review of complete applications will begin November 1, 2016, and will continue until the position is filled.

USC is an equal-opportunity educator and employer, proudly pluralistic and firmly committed to providing equal opportunity for outstanding persons of every race, gender, creed and background. The University particularly encourages women, members of underrepresented groups, veterans and individuals with disabilities to apply. USC will make reasonable accommodations for qualified individuals with known disabilities unless doing so would result in an undue hardship. Further information is available by contacting uschr@usc.edu.

Tenure Track Faculty Position in Global Geophysics, University of Southern California

The Department of Earth Sciences in the Dana and David Dornsife College of Letters, Arts and Sciences of the University of Southern California in Los Angeles, California, invites applications for a faculty position in global geophysics at the tenure-track Assistant Professor or tenured Associate Professor level. We seek candidates who will develop a program of fundamental research on the structure, deformation, and/or evolution of the lithosphere and its interactions with the Earth's deep mantle and fluid envelopes. The successful candidate will bring new approaches—observational, experimental, computational, and/or theoretical—to lithospheric studies and will demonstrate a strong commitment to both graduate and undergraduate teaching. We are particularly interested in candidates who can connect research on lithospheric

Faculty Positions in Environmental Science and Engineering South University of Science and Technology in Shenzhen, China

The South University of Science and Technology (known as SUSTC or SUSTech) (http://www.sustc.edu.cn/en) is a public university founded in the Shenzhen Special Economic Zone of China. It is intended to be a top-tier international university that excels in interdisciplinary research, nurturing innovative talents and delivering new knowledge to the world. SUSTC is conducting a global search for talented faculty who are also innovators and trailblazers. Founded since 2015, the School of Environmental Science and Engineering at SUSTC aspires to become a center of excellence for cutting-edge and multidisciplinary environmental research. We invite applications for tenure-track and tenured faculty positions in broadly defined environmental science and engineering. Research areas include but are not limited to: hydrology and water resource engineering, water pollution and treatment, atmospheric chemistry, air pollution control, solid waste utilization, ecosystem assessment, environmental remote sensing, and global change. Positions are immediately available at all ranks. Highly competitive salaries and start-up packages will be provided. The successful candidates will have great opportunities to advance environmental research in China as the country faces up to enormous challenges in achieving environmental sustainability.

Applicants should have a Ph.D. degree in a water, air, or earth system related discipline. Candidates must have a proven track record of high-quality scientific publications and must have excellent communications skills. Those interested are invited to apply by submitting the following material electronically to iese@sustc.edu.cn: 1) Curriculum Vitae (with a complete list of publications); 2) Statement of research interests; 3) Statement of teaching philosophy; 4) Selected reprints of three recent papers; and 5) Names and contact information of five references. Review of applications will begin immediately and continue until the positions are filled.

ASSISTANT PROFESSOR, IGNEOUS PROCESSES, UNIVERSITY OF UTAH:

The Department of Geology & Geophysics at the University of Utah invites applications for a tenure-track Assistant Professor position in Igneous Processes beginning fall semester 2017. Applicants must have a Ph.D., and the successful candidate will be expected to build a productive and internationally visible research program. We will consider candidates in a broad range of igneous specialties, including one or more of igneous petrology, volcanology, igneous geochemistry including radiogenic isotopes/geochronology, and magma physics/fluid dynamics (e.g., physical processes of magma formation, diffusive and advective mass transfer in magmas, eruption and crystallization processes). We particularly welcome candidates applying integrated field, laboratory and computational approaches to igneous systems. The Department of Geology and Geophysics is housed in the Frederick A. Sutton Building, a new state of the art teaching and research facility. Available research tools include LA-MC-ICP-MS, the SIRFER stable-isotope facility, noble-gas mass spectrometry, electron microprobe, QEMSCAN, paleomagnetic and rock magnetic facilities, and access to the University's Surface Analysis Center and the Center for High Performance Computing. Opportunities also exist for professional interactions outside the department with personnel at the University of Utah's Energy and Geoscience Institute, the Utah Geological Survey and the United States Geological Survey. Applications should be received by September 30, 2016 for full consideration; however, applications received after that time may be considered until the position is filled. To apply, upload a statement of teaching and research interests, curriculum vitae, names and contact information for three references to: utah.peopleadmin.com/postings/52715. If you have specific questions about the position please contact J.R. Bowman [john.bowman@utah.edu]. Information about the Department of Geology and Geophysics can be found at: http://www.earth.utah.edu.

The University of Utah is an Equal Opportunity/Affirmative Action employer and educator. Minorities, women, and persons with disabilities are strongly encouraged to apply, and the University provides reasonable accommodation to the known disabilities of applicants and employees. Veteran's preference is extended to qualified applicants. The University of Utah values candidates who have experience working in settings with students from diverse backgrounds, and who possess a strong commitment to improving access to higher education for historically underrepresented students.

problems to other areas of departmental interest, which include global environmental change, geobiology, and earthquake system science (http://dornsife.usc.edu/earth/). Applicants must have a PhD in a related field.

Applications should include a curriculum vitae, publication list, statement of teaching and research interests, and three or more names of individuals familiar with the applicant's work who could be contacted for letters of reference. In order to be considered for this position, applicants are required to submit an electronic USC application through the following link: http://jobs.usc.edu/postings/67388. Inquiries can be directed to: Chair, Search Committee, c/o Karen Young (kayoung@usc.edu). Review of complete applications will begin November 1, 2016.

USC is an equal-opportunity educator and employer, proudly pluralistic and firmly committed to providing equal opportunity for outstanding persons of every race, gender, creed and background. The University particularly encourages women, members of underrepresented groups, veterans and individuals with disabilities to apply. USC will make reasonable accommodations for qualified individuals with known disabilities unless doing so would result in an undue hardship. Further information is available by contacting uschr@usc.edu.

FACULTY POSITION IN ATMOSPHERIC SCIENCES (DYNAMICS)
Stanford University

FACULTY POSITION IN ATMOSPHERIC SCIENCES (DYNAMICS)
Stanford University

The Department of Earth System Science at Stanford University invites applications for a tenure-track faculty appointment in the area of Atmospheric Sciences. The primary focus of the search is in atmospheric dynamics, although candidates with interests in the broader atmospheric sciences are also encouraged to apply. We are searching for a creative and innovative scholar with a demonstrated research record who is also committed to high-quality undergraduate and graduate teaching, including a demonstrated ability or potential in teaching and mentoring a diverse student body (such as women, minorities, and others from underrepresented backgrounds). The level of the appointment is open, with a preference for candidates at the junior rank.

We seek an expert who studies the role of atmospheric dynamics in shaping climate system variability and change. Although we are open to a broad range of specific expertise and research topics, we are seeking to add expertise in understanding the fluid dynamics of the atmosphere within the context of the Earth System. Particular areas of emphasis could include the hydrological cycle, atmosphere-ocean and/or atmosphere-sea ice coupling, tropical meteorology, eddy-mean flow dynamics, stratospheric dynamics, the dynamics of extreme weather and climate events, and feedbacks between the atmospheric circulation and atmospheric constituents such as trace gases and aerosols.

A candidate's tools and methods may be theoretical, computational and/or observational, with potential to establish a vigorous research program, preferably grounded in geophysical fluid dynamics. In addition, because a wide range of scientific challenges offer compelling prospects for future breakthroughs, the successful applicant will also have demonstrated interests in interacting effectively with a broad range of colleagues, such as in the School of Earth, Energy and Environmental Sciences, the Stanford Woods Institute for the Environment, or outside institutions. The successful applicant is also expected to teach classes and mentor graduate students in the Department of Earth System Science, and to teach in the Earth Systems undergraduate program.

Please apply online with the following application materials: cover letter, curriculum vitae, a statement outlining research and teaching experience and interests, and the names and addresses of three or more referees, at https://academicjobsonline.org/ajo/jobs/7555. The search committee will request letters of recommendation for a subset of applicants following review of these materials. Review of applications will begin October 1, 2016. Applications will continue to be accepted until the position is filled.

Stanford University is an equal opportunity employer and is committed to increasing the diversity of its faculty. It welcomes nominations of and applications from women, members of minority groups, protected veterans and individuals with disabilities, as well as from others who would bring additional dimensions to the university's research, teaching and clinical missions.

Postcards from the Field

Hi, Everyone.

At the second Deep Carbon Observatory Summer School in Yellowstone National Park this July, 35 early-career scientists from around the world participated in a field sampling day to explore the geochemistry and microbiology of hydrothermal systems outside the park. Here, Moyosore Ajayi (left; Vanderbilt University, USA) and Ery Hughes (right; University of Bristol, UK) are flushing the chamber of a carbon dioxide flux meter before taking another measurement of carbon dioxide fluxes released from the soil. The Summer School was led by Rick Colwell (Oregon State University, USA) and a team of nine additional instructors. To learn more about the Summer School and the Deep Carbon Observatory, visit deepcarbon.net or follow us on Twitter @deepcarb #DCOSS16.

—Katie Pratt, Communications Director, Deep Carbon Observatory

This page has been corrected from the version printed in the 15 September magazine to reflect Dr. Pratt's correct affiliation and remove an incorrect attribution for the photograph.

View more postcards at
http://americangeophysicalunion.tumblr.com/tagged/postcards-from-the-field.

Organizational Partner Spotlight:

W1M3A Marine Observatory of the National Research Council of Italy

CO2-Pro instrument from the W1M3A observatory after a year long deployment

Why We Support AGU

Why does your organization see value in being a Partner of AGU?

As a company that provides solutions to a broad range of hydrosphere applications, Pro-Oceanus values the extensive and diverse community of scientists and engineers that the AGU brings together.

What impact does AGU science have on your industry or business?

The science conducted by AGU members guides the direction of Pro-Oceanus research and development of oceanographic instrumentation.

What do you wish the general public knew about AGU's impact and the impact of Earth and space science?

It is important to know that the AGU provides resources and information about local and world issues in Earth and Space science that is useful to not only scientists and engineers, but also educators and the general public.

Which areas of the Earth and space sciences are of most importance to your business?

Oceanography and Limnology are the most important scientific areas for Pro-Oceanus. Climate change and ocean acidification are two concerns that Pro-Oceanus addresses through research and collaboration with researchers around the World.

Why should other organizations support AGU and look into becoming an Organizational Partner?

The AGU reaches more researchers dedicated to the advancement of Earth and Space science than any other organization. The AGU's ability to connect a broad base of scientists as well as focused groups of individuals with Organizational Partners is of immense value.

The Organizational Partnership program helps develop relationships that align with AGU's values and mission. Pro-Oceanus is a proud partner with AGU; their funding has helped to support, among other things, the 2016 Ocean Sciences Meeting.